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VOLUME II.

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ELECTRIC LIGHTING AND POWER DISTRIBUTION.

VOL. II.

ELECTRIC LIGHTING AND POWER DISTRIBUTION.

AN ELEMENTARY MANUAL OF ELECTRICAL ENGINEERING

SUITABLE FOR

STUDENTS PREPARING FOR THE PRELIMINARY AND ORDINARY GRADE EXAMINATIONS OF THE CITY AND GUILDS OF LONDON INSTITUTE.

BY

W. PERREN MAYCOCK, M.I.E.E.

CONSULTING ELECTRICAL ENGINEER.

(IN TWO VOLUMES)

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PREFACE.

After much delay, for which the Author begs to tender his apologies, this Volume II. is now laid before its future readers. The retardation has been due to various causes, but chiefly to the bringing out of other works which the writer felt impelled to finish first. One of these, *The Alternating-Current Circuit,* now forms Chapter XI. in the present volume; though it will still continue to be published, with slight additions, as a separate book. Another, *Electric Wiring, Fittings, Switches, and Lamps,* which was originally intended eventually to form part of this Volume II., will, owing to the matter of bulk, have to remain a separate and supplementary volume.

In the early work on this book the Author received much kind assistance from Mr. Charles H. Yeaman; and, in its completion, very material help, in the way of revision and the initial preparation of the drawings, from Mr. Llew. R. Lester. Sincere thanks are tendered to both of these gentlemen.

With the double object of rendering the matter as correct—and the phraseology as clear—as possible, the work has been subjected to repeated and very close revision.

W. P. M.

Waddon, Surrey,
August, 1903.

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NOTE.—Students preparing for the *Preliminary Examination* of the City and Guilds of London Institute need only read those paragraphs which are marked by asterisks. Questions relating to the Preliminary Syllabus are similarly distinguished.

ELECTRIC LIGHTING

AND POWER DISTRIBUTION.

AN ELEMENTARY MANUAL OF ELECTRICAL ENGINEERING.

VOLUME II., 1903.

CHAPTER X.

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.); and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

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*1. CHARACTERISTIC CURVE.—In Chap. *VI.* a "curve" was defined as a diagram in which a *curved* or *straight* line is employed to represent the relation of certain varying quantities to each other. A "curve" may also have a zigzag form. When one of the two quantities to which the "curve" relates increases or decreases in direct proportion to the other, the "curve" takes the form of a straight line. When one increases or decreases gradually with respect to the other varying quantity, but not in direct proportion, the "curve" is truly a curve. When one or both quantities change suddenly, the "curve" is a zigzag line.

The term *characteristic curve* is used in the same sense, but generally refers to the characteristic qualities of a dynamo, alternator, or motor.

We saw in Chap. *VI.* that curves of induction are of great service in rendering our ideas of magnetism precise. In the same way that these enable us to deduce the behaviour of different samples of iron or steel under different magnetic forces, so the characteristic curves of dynamos tell us at a glance how a machine will act under given circumstances. It will be evident, from what has already been said, that a "curve" may represent the variation of

one quantity when we intentionally vary another, provided the two quantities are related in some definite manner to each other.

*2. CHARACTERISTIC CURVE AND BEHAVIOUR OF A SERIES DYNAMO. ARMATURE REACTION.—Fig. 1 shows the characteristic curve of a series dynamo, and should be studied in conjunction with Fig. 2, where a diagram of the connections of such a machine is given. In plotting this curve, the dynamo was driven at a speed of 1000 revolutions per minute, and the resistance in the external circuit was varied so as to give different currents: the resistance being high to start with, and reduced for each succeeding test. The current values were obtained from an ammeter placed in the circuit, while the corresponding pressures or P.Ds. were measured by a voltmeter connected across the dynamo terminals. Abscissæ, or horizontal distances (Chap. *VI.*), represent amperes; and ordinates, or vertical distances, the volts P.D. at the terminals.

The curve was got by first marking the position of certain points on the paper, and then drawing a curved line (by the help of a flexible wood batten for instance) which passed through as many of these points as possible. Each of these points represents the result of a test. Thus, suppose that when the ammeter indicates a current of 10 amperes, the P.D. observed at the terminals is 87 volts. Running our finger along the abscissæ, we come to a line representing 10 amperes, and on the ordinates we take a line the proper number of divisions up to represent 87 volts: follow these two lines until they intersect, and the point of intersection is a point on our curve. Now slightly reduce the resistance, and suppose the current is then 20 amperes,

and the P.D. 178 volts: pick out the corresponding abscissa and ordinate, and where these intersect we have another point on the curve. These and succeeding points got by further reducing the resistance step by step, and observing the resulting P.D. and current, are indicated by the crosses.

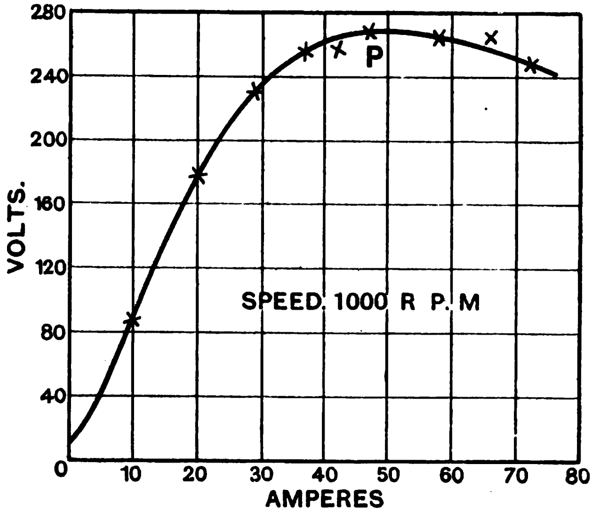

FIG. 1.—Characteristic Curve of a Series Dynamo.

Thus, in plotting a curve of any kind, it is necessary to make a series of observations which will give points well separated on the paper, taking a sufficient number to show any peculiarities at any part, and then draw a line which shall pass through as many of them as possible. Some of the points may be left untouched on one side

and some on the other, this being due to slight errors of observation. When once the curve has been obtained, we may compare any pair of corresponding values at any place on the curve.

In this and other curves illustrated herein, only the main abscissæ and ordinate lines are shown in the diagram, the intermediate ones being left out to render the figure clearer. The appearance of an actual small piece of "squared paper" is shown full size in Chap. *VI.*; and

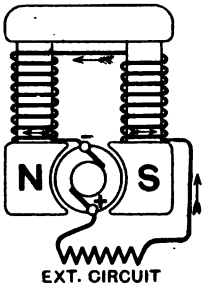

FIG. 2.—Connections of a Series Dynamo.

when it is remembered that a curve like that in Fig. 1 is originally drawn on a sheet perhaps a foot square, or even larger, it is evident that the intermediate lines must be omitted when the curve is reduced in size.

Referring again to the curve in Fig. 1, from a reference to Fig. 2 it will be clear that the greater the resistance in circuit with a series machine, the less will be its E.M.F. and current at a given speed: while if the circuit resistance be gradually diminished, the E.M.F. and current will increase as long as the F.M. is not

saturated. A few series machines give their greatest current when short-circuited, and every care has to be taken to prevent such a thing occurring, as it would probably result in the burning out of the armature and F.M. coils. In others, the armature reaction (see below) is so great that the current on short circuit is not excessive. A series dynamo in this respect differs essentially from a shunt dynamo, for if the terminals of the latter be short-circuited (Fig. 3), the effect is to shunt all the current from the F.M. coils, so that the E.M.F. drops practically to zero.

In plotting the curve of a series machine, we first start with so high a resistance in the external circuit, that the volts and amperes given are very few. Thus we obtain the first point on the curve. Diminish the resistance slightly, and the P.D. and current will increase. In each succeeding observation, the resistance is diminished, and thus the values for P.D. and current get higher and higher. At length, however, though the current continues to increase, the P.D. drops owing to the F.M. becoming saturated, and to the *reaction of the armature*. The cause of the latter is as follows. The effect of the current circulating in a ring or drum armature is to magnetize the core in a direction at right angles with the direction of the field of the dynamo. This *cross-magnetization* tends to react upon and weaken the field in which the armature is placed, and this reaction increases as the current drawn from the armature is increased. The armature also reacts upon and weakens the field in many other ways which cannot be considered here.

When a curve has been drawn, it will resemble that

shown in Fig. 1, for the curves of all series machines are more or less alike. On examining the curve, it will be noticed that at first the volts increase very rapidly for a given increase in the current: this is caused by the increasing current round the F.Ms. giving rise to more lines of force in the field. After a time, however, the curve begins to bend more and more, and eventually it droops towards the base. This shows, that after a certain stage a given increase in the current gives fewer additional lines to the field, and consequently the E.M.F. increases but slowly: this being due to the cores of the F.Ms. becoming saturated. The armature reaction before alluded to then becomes overpowering, and the curve turns downwards.

It will be seen that the curve does not begin exactly at zero, but a little way up the vertical line. This indicates the existence of a small E.M.F. before the current begins to flow, *i.e.* when the dynamo is on open circuit; this E.M.F. being due to the residual magnetism of the F.M. cores, without which no machine could excite itself. If the machine be run at different speeds, the resultant curves will vary as to pressures, but they will all have the same general shape.

*3. INTERNAL AND EXTERNAL CHARACTERISTIC CURVES. —A curve (such as the one just described) which gives the relation between the current and the terminal P.D. is called an *external characteristic;* to distinguish it from an *internal characteristic*, i. e. a curve showing the relation between the current and the E.M.F. generated in the machine. The external characteristic is not only more useful, but is easier to plot than the internal characteristic, for the reason that in the latter case the E.M.F. has

to be got by calculation, such as by multiplying together the current and the total resistance of armature, F.Ms., and external circuit; allowance having to be made for armature reactions. The P.D. at the terminals, on the other hand, the volts of which we use for getting out an external characteristic, is easily and correctly read off by means of a voltmeter.

In speaking of the *characteristic curve* of a dynamo, it is the *external characteristic* which is generally implied.

4. SERIES DYNAMOS FOR ARC LIGHTING.—Dynamos for series arc lighting (§§ *179* and *196*) are generally series wound, the current having to be kept constant while the circuit resistance varies owing to fluctuations in the positions of the lamp carbons, or to alterations in the number of lamps in circuit. The characteristic curve which should be given by a machine for such work is known as a *drooping characteristic.* The cause of this drooping is due, among other things, to the early saturation of the F.M. cores, and the consequent increased effect of the reaction of the armature (§ 2). It follows from this that dynamos for this work must have comparatively little metal in their magnets, or else metal of low permeability.

Let us try to understand how a machine with a drooping characteristic fulfils the necessities of a series arc-lighting circuit. Starting from the point P (Fig. 1), where the curve begins to bend downwards, it is evident that as the current values increase the terminal pressure decreases. Now as the current in a circuit cannot possibly increase while the P.D. decreases unless the circuit resistance decreases more rapidly than the P.D., it follows that a considerable decrease in the resistance of the arc lamp

circuit—due, say, to the feeding forward of some of the carbons, or to the cutting out of two or three lamps—tends to produce but a small increase of current, and that this latter is opposed by a corresponding decrease of pressure. On the other hand, an increase of the circuit resistance—due, say, to the lengthening of some of the arcs, or to the switching in of lamps—tends to produce a small diminution of the current, and this tendency is counterbalanced by a corresponding increase of pressure.

This self-regulating effect is not sufficient compensation for any material alteration in the number of lamps in circuit; variations in circuit resistance due to this being provided for by some kind of automatic regulator, that in use on the Thomson-Houston arc dynamo being illustrated in § 198 in the fourth and previous editions of Vol. I. Special dynamos for series arc lighting are not very much used now-a-days, the general practice being to run the lamps in series groups of two, three, four or more off the ordinary constant potential supply mains (Chaps. I. and XVII.).

*5. Characteristic Curve and Behaviour of a Shunt Dynamo.—A shunt dynamo is very different in action from a series dynamo. From Fig. 3 it will be clear that, unlike the series machine, a shunt machine gives the greatest P.D. at its terminals when the external circuit resistance is greatest; as then practically all the current goes round the F.M., which latter is consequently magnetized to its greatest power. As the resistance of the external circuit diminishes, the drop of volts (Chaps. *III.* and **IV.**) caused by the armature resistance increases; and the excitation of the field magnet, and the P.D. at the terminals, diminish. Suppose, for the sake

of argument, that the external resistance were equal to the F.M. resistance; half the total current would then pass through the external circuit, and half round the F.M. If the external resistance were still further decreased, more current would pass through the external than through the F.M. circuit: and this is the usual condition of things, the F.M. coils having 30 or 40 or more times the resistance of the external circuit. With every decrease in the external circuit resistance, the E.M.F. of

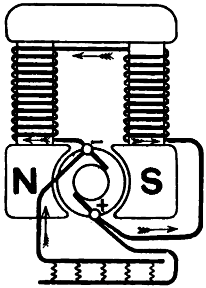

FIG. 3.—Connections of a Shunt Dynamo.

the machine and the P.D. at its terminals will decrease. In other words, a shunt dynamo is not a constant potential machine, unless specially well designed, for the E.M.F. induced in the armature changes with every variation of the external circuit resistance. If the external circuit resistance be very low indeed, as would be the case if the terminals of the machine were short-circuited by a short, thick cable, practically all the current will be shunted off the F.M., and the E.M.F. of the machine, and also the P.D. at its terminals, will drop almost to zero.

In these respects it will be seen that the action of a shunt machine is the reverse of that of a series machine.

Fig. 4 illustrates the general form of the characteristic curve obtained from a shunt-wound dynamo.[1] It is the external characteristic, as the ordinates represent the volts or pressure at the terminals, not the total E.M.F. (§ 3). The little crosses indicating in Fig. 1 the different observ-

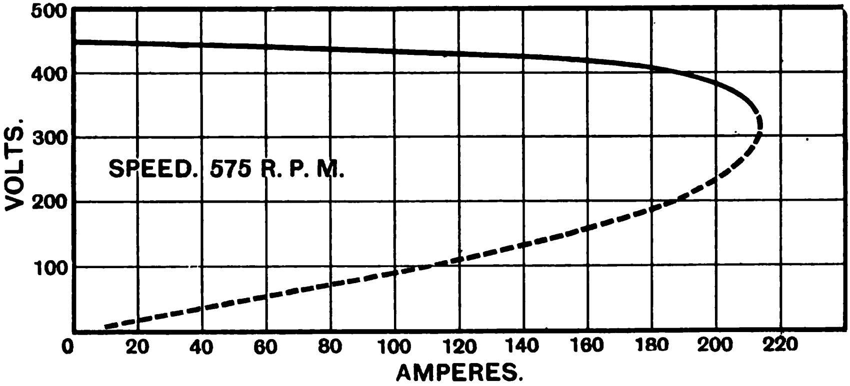

FIG. 4.—Characteristic Curve of a Shunt Dynamo.

ations which were made, and which gave various points on the curve, are omitted from the present figure.

Starting with the external resistance so great that there was no current in the outer circuit, that is, with the external circuit broken altogether, the P.D. was at its maximum, viz. about 450 volts. When the resistance was so far reduced as to give about 60 amperes, the P.D. fell

[1] This curve was taken from a 2-pole, 100 k.w. machine recently built by Messrs. Ernest Scott and Mountain.

to 440 volts. When the current was 120 amperes, the P.D. had fallen to 430 volts, and when the current had further increased to 187 amperes the pressure was 400 volts. At 210 amperes we see that it had fallen to about 350 volts.

It is obvious that there must be some limit to the increase of current in the external circuit. At first, the amount of current shunted from the field magnets makes very little difference in the strength of the field, and consequently the P.D. falls but slightly. After a time, however, the P.D. begins to fall faster, and the curve droops more and more sharply. At last a point is reached (in this case when the current is 214 amperes, and the P.D. at terminals 315 volts) when the volts begin to decrease faster than the resistance: and in consequence, the current begins to decrease, and the curve if continued takes a backward turn. This goes on until the external resistance is at its lowest, and the volts, and consequently the amperes also, have fallen to zero. As there is always a certain amount of residual magnetism in the F.Ms., the curve ought to end a short distance to the right of zero, indicating the existence of a very small current.

This latter portion of the curve is unstable, and is therefore dotted in. In other words, though the speed and circuit resistance be kept constant, the pressure and current will vary in a most erratic manner. The reason of this is that the pressure at the terminals has dropped to a value too small to send a sufficient magnetizing current round the field magnet, so that the magnetization of the latter, having been gradually reduced from the maximum, and being in consequence hyper-residual, is unstable, and liable to fall

away by fits and starts. It may be mentioned that the dotted part of the curve in Fig. 4 is not the result of experiment, but has been drawn in from knowledge of the form this portion of the curve would generally take.

*6. BEHAVIOUR OF SERIES AND SHUNT DYNAMOS ON SERIES AND PARALLEL CIRCUITS.—A number of devices, such as lamps, are arranged either in series or in parallel. The insertion of additional lamps on a series circuit increases its resistance, but on a shunt or parallel circuit the resistance is decreased thereby. Conversely, the cutting out of lamps on a series circuit diminishes the circuit resistance, while on a parallel circuit the resistance would be increased (Chap. **IV**.).

It is interesting to notice the behaviour of simple series and shunt machines under such circumstances. In Fig. 5 (*a*) a series machine is represented as joined up with a series lamp circuit, on which it is essential that the current be kept constant. If lamps are switched "on" or "off," the resistance will be respectively increased or decreased; and the current will in the first case decrease and in the second case increase. Hence ordinary series machines are of little use under such circumstances, without the addition of regulating devices (§§ 4 and 13). The matter, however, is greatly dependent on the size and design of the dynamo, as large well-constructed series machines will work very satisfactorily on variable series circuits (§ 4).

In Fig. 5 (*b*) we have a series dynamo joined up with a parallel circuit. Here the insertion of fresh lamps decreases the resistance, and *vice versâ*. On a parallel lamp circuit it is necessary to keep the pressure constant; but in this case the pressure will be anything but constant.

Starting with fewest lamps in circuit, the pressure will be

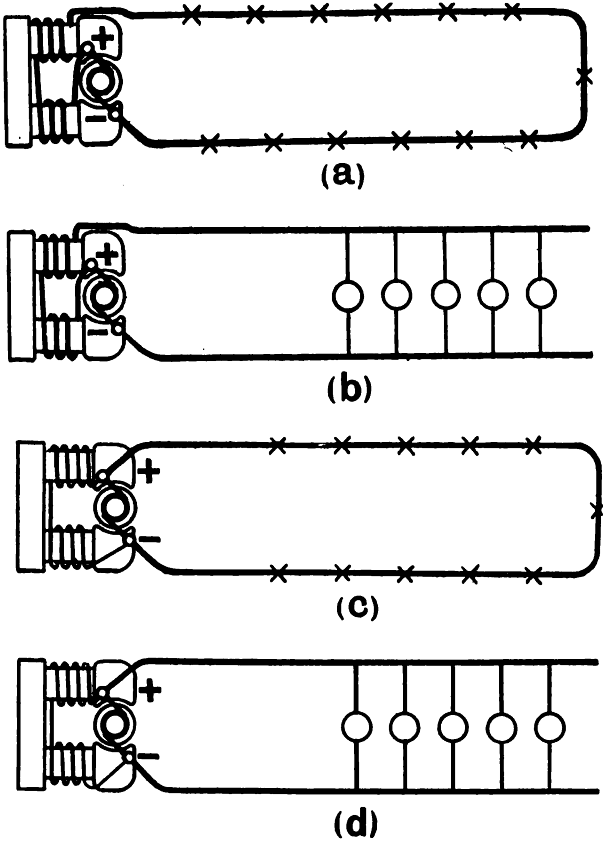

FIG. 5.—Connection of Series and Shunt Dynamos to Series and Parallel Circuits.

very low indeed, but will gradually rise to a maximum as

more lamps are added. During a slight further increase in the number of lamps the pressure will remain fairly constant, but will afterwards gradually drop as more are connected in circuit. Hence a plain series dynamo is of no use for this work.

In Fig. 5 (*c*) a shunt machine is shown joined up with a series circuit, where, it will be remembered, the current has to be kept constant. In this case, if the circuit resistance be increased from a low value by the addition of lamps, the current will first of all increase very rapidly; then, as a few more lamps are added, remain fairly constant; and lastly, with a further increase of resistance, decrease rapidly. The action of a shunt machine on a variable series circuit is thus very erratic. Unless the variation of the external circuit resistance is limited, a shunt dynamo cannot be depended upon for such a service.

In Fig. 5 (*d*) a shunt machine is shown in conjunction with a parallel circuit. When there are few lamps in circuit, *i. e.* when the resistance is greatest, the P.D. at the terminals will be a maximum. This P.D. will remain fairly constant as more lamps are added, until the circuit resistance is reduced to a certain value, whereupon the terminal pressure will begin to fall very rapidly, and will eventually drop to zero. With a large machine, the variation of pressure, within certain limits, would be inappreciable, as long as the lamps were situated near to it; the reason for which proviso is given in the next paragraph.

In connection with shunt or compound dynamos, it may be pointed out that it is dangerous to lift the brushes, or to break the shunt circuit in any way, while the machine is running. If the dynamo is on open circuit, the *spark-*

wear (§ 39) at the commutator or at the point of break, and the possibility of shock, will be considerable; the latter especially if the attempt is made to raise both brushes at the same time. This is chiefly due to the momentary E.M.F. of inductance in the field coils, which may in some cases be sufficiently great to break through their insulation. If the machine is supplying glow lamps direct, and the lamp circuit is closed, the E.M.F. induced in the field coils by raising one or both of the brushes, is likely to cause a momentary flash-up of the lamps, and may burn some of them out.

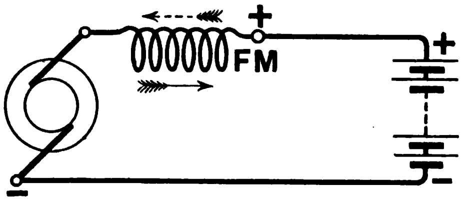

FIG. 6.—Series Dynamo and Battery.

Generally speaking it is inadvisable to raise the brushes of any dynamo while it is running, unless the field coils be first either switched out or shunted through a resistance.

* 7. REVERSAL OF POLARITY OF DYNAMOS.—In some circuits there is an active opposing electro-motive force set up, as, for instance, in the charging of secondary batteries. If the dynamo E.M.F. fall below the battery E.M.F., the latter sets up a current round the circuit in the reverse direction. Suppose a series dynamo is joined up with a battery, as represented in Fig. 6; then the direction of the dynamo current through the F.M. coil is

indicated by the firm line arrow. Now if from any cause, such as a temporary slowing down of the engine, the dynamo E.M.F. should fall below that of the battery, the latter will send a current through the F.M. in the direction shown by the dotted arrow. This, unless the dynamo recover itself very quickly, will result in the reversal of the polarity of the machine; and the dynamo E.M.F. will then work in conjunction with the battery E.M.F., thus setting up a very heavy current in the wrong direction, and endangering both generator and battery.

Such a state of things cannot occur with a shunt

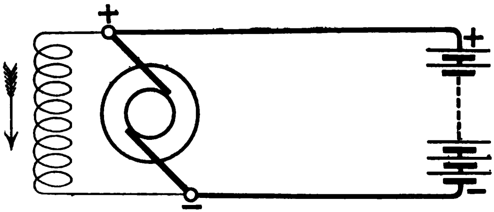

FIG. 7.—Shunt Dynamo and Battery.

machine, as will be clear from Fig. 7. If the battery E.M.F. does overcome that of the dynamo, the current round the F.M. will still be in the proper direction, so that a reversal of polarity is not possible. Such an occurrence would tend to strengthen the field of the machine, and help it once more to overcome the battery E.M.F., when the speed was again raised.

With compound machines there is some risk of reversal of polarity when used for battery charging, but not so much as with series machines: and the risk is slightly greater with short-shunt (Fig. 8) than with long-shunt

(Fig. 9) dynamos. It depends on the relative ampere-turns of the shunt and series coils, and on the resistance of the armature. If the latter is so low as (when stationary) to allow the ampere-turns in the series winding to

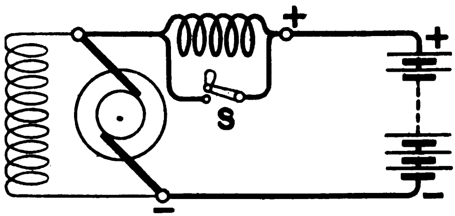

FIG. 8.—Short-shunt Compound Dynamo and Battery.

exceed those in the shunt winding, then reversal will take place. It will be seen on reference to the figures that if the battery current runs back through the dynamo, the shunt and series windings act in opposition, and reversal

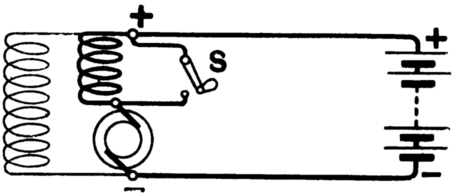

FIG. 9.—Long-shunt Compound Dynamo and Battery.

would take place only if the exciting power of the series winding exceeded that of the shunt. The difficulty could be avoided by connecting a switch across the terminals of the series coil, as shown at *S* in Figs. 8 and 9, and keeping the latter short-circuited until the machine was started.

For the above reasons shunt machines are always best for use in charging secondary cells; and for other work, such as electro-metallurgical processes, where there is a tendency towards reversal of polarity.

*8. CHARACTERISTIC CURVE AND BEHAVIOUR OF A COMPOUND DYNAMO.—Dynamos are now as a rule required to maintain a constant potential on parallel distribution mains. In incandescent lighting, for instance, it is necessary for the machine to keep up a constant P.D. between the + and − mains, even though the resistance due to the number of lamps in circuit may alter very considerably. A series machine or a poorly-designed shunt machine would be quite unsuitable for such work; for the P.D. at the terminals of either would alter with every variation of the external circuit, *i. e.* with every alteration in the number of lamps in use. A good shunt machine, however, can maintain a fairly constant potential at its terminals up to a certain point, but this is not all that is wanted in cases where a long pair of "feeders" carries the current to the distributing mains. The drop of volts in these feeders varies with the current demand, and when the latter is high the drop is increased, so that an increase in the P.D. at the dynamo terminals is required to make up for the loss. Now as the voltage of a shunt machine is at its highest possible value when the external resistance is greatest, it is obviously unsuitable in such a case as above. A compound machine, as will presently be shown, may be arranged to fulfil the above conditions.

It will now be demonstrated that a combination of the series and shunt methods of excitation, as used in compound machines, is self-regulating through a circuit of

variable resistance. With a compound machine (Fig. 10), if the external resistance increases, the terminal P.D. due to the series coil diminishes, while that due to the shunt coil increases, and *vice versâ.* If a machine is wound with series and shunt coils so proportioned that the P.D. due to the one increases exactly as that due to the other diminishes, or the reverse, it is evident that the machine will be self-regulating within practical limits of change of external resistance. When the external resistance is high, the shunt

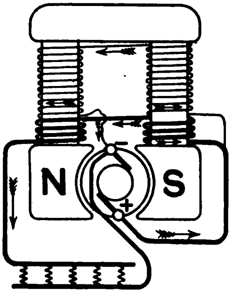

FIG. 10.—Connections of a Compound Dynamo (Short Shunt).

coil furnishes practically all the excitation; but when it is low, the series coil helps the shunt. At any value of the external circuit resistance, within the working limits, the sum of the P.Ds. due to both series and shunt coils should be equal to the total P.D. required. The characteristic curve of a good compound machine is thus a horizontal line or nearly so.

By making the series coil proportionally more powerful than the shunt, the characteristic curve will rise slightly as the current increases. This rise of P.D. may be mad

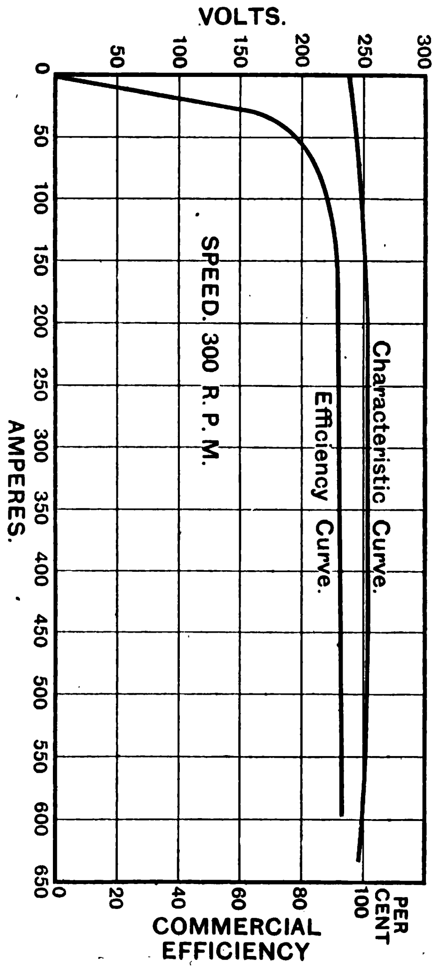

FIG. 11.—Characteristic Curve of a Compound Dynamo.

just sufficient to compensate for the loss of volts in long feeders, and then the machine will maintain a constant P.D. at a distant point of consumption of the current (§ 218). Such a machine is said to be *over-compounded*, and to have a *rising characteristic.*

The external characteristic of a 150 k.w. compound dynamo[1] for traction work is given in Fig. 11. The maintenance of uniform pressure in such work is not so necessary as in lighting, so that the machine is only partly over-compounded. It should be noticed that the variation of voltage between 100 and 600 amperes does not exceed 5 or 6. The variation of 10 volts between 0 and 100 amperes is negligible, as the machine would probably very seldom be called upon to work with such light loads. This figure also gives the efficiency curve of the dynamo, an explanation of which will be found in the next paragraph.

A compound machine is only self-regulating when it is run at its proper speed.

9. Efficiency of Dynamos.—A portion of the power used in driving a dynamo is not converted into electrical energy at all, but is wasted in friction at the bearings, brushes, etc. Again, the electrical power developed by a dynamo is not all available for use in the external circuit, for part has to be expended in exciting the F.Ms., and part is wasted in the machine, in the form of heat developed in the coils and cores, etc.

The power which is expended in driving the machine is called the *input ;* while that which is given to the ex-

[1] Built by Messrs. Ernest Scott and Mountain.

ternal circuit is termed the *output* or *useful power* of the machine.

The *input* of a machine is the power (expressed in H.P.) required to drive it.

The *output* of a machine is the P.D. at the terminals multiplied by the current supplied to the external circuit; and is thus first expressed in watts or kilowatts.

Example.—If a dynamo give a current of 250 amperes at 220 volts, its output is 55,000 watts or 55 kilowatts; and it is termed a 55 k.w. machine. Similarly one giving 1000 amperes at 1000 volts is a 1000 k.w. machine.

The *efficiency* of dynamos is of three kinds—*mechanical, electrical*, and *commercial.*

The *mechanical efficiency*, or *efficiency of conversion*, is a measure of the capability of a dynamo to convert mechanical energy into electrical energy. Thus:—

Mechanical efficiency in % =

$$\frac{\text{Total electrical power developed} \times 100.}{\text{Total mechanical power used in driving.}}$$

Both the mechanical and electrical power must be expressed in the same units, say in watts, kilowatts, or H.P. (Chap. *I.*).

EXAMPLE.—*What is the mechanical efficiency of a dynamo which takes* 140 *H.P. to drive it, when it is generating a total electrical power (including that wasted in the machine itself) of* 100,000 *watts?*

$$\text{Mechanical efficiency in } \% = \frac{100{,}000 \times 100}{140 \times 746} = \frac{10{,}000{,}000}{104{,}440} = 95 \cdot 75 \ \%$$

The *electrical efficiency*, or *economic co-efficient*, is a measure of the capability of a dynamo to yield the electrical energy

generated within it for useful work in the external circuit. Thus :—

$$\text{Electrical efficiency in } \% = \frac{\text{Electrical power given to external circuit} \times 100.}{\text{Total electrical power generated.}}$$

EXAMPLE.—*What is the electrical efficiency of a dynamo which generates a total power of* 100,000 *watts, of which* 430 *amperes at* 220 *volts are delivered to the external circuit?*

$$\text{Electrical efficiency} = \frac{430 \times 220 \times 100}{100{,}000} = 94{\cdot}6\ \%$$

The *commercial* or *nett efficiency* is that which most directly concerns the electrical engineer, as it misses the above two intermediate stages, and expresses how far the dynamo is commercially useful as a converter of energy. In other words, it gives the ratio of the *output* to the *input*, both of these being expressed in the same units. Thus :—

$$\text{Commercial efficiency in } \% = \frac{\text{Electrical power given to external circuit} \times 100.}{\text{Mechanical power absorbed in driving.}}$$

EXAMPLE.—*A dynamo takes* 140 *H.P. to drive it, and supplies* 430 *amperes at* 220 *volts to the external circuit. What is its commercial efficiency?*

$$\text{Commercial efficiency in } \% = \frac{\text{Output} \times 100}{\text{Input.}} = \frac{430 \times 220 \times 100}{140 \times 746} = \frac{9{,}460{,}000}{104{,}440} = 90{\cdot}6\%$$

both output and input being conveniently expressed in watts. This means to say, that for every 1000 watts put in, about 906 will be given out to the external circuit.

When the term *efficiency* is used alone, it is generally the *commercial efficiency* which is understood. The commercial efficiency of any given type of direct-current

machine is the greater the larger the machine. It varies from about 80% in the smallest practical sizes, up to 95% in large ones. With any given machine the efficiency is not a constant quantity, being less at light than at medium or full load. When the dynamo is on open circuit, its efficiency is nil, for it is doing no useful work. Fig. 11 gives the efficiency curve of the traction generator alluded to in the preceding paragraph. From this we see that when the output is 25 amperes the efficiency is only 60%, at a little over 50 amperes it is 80%, while from 100 to 600 amperes it rises gradually from about 88% to 93%.

Certain 240 kilowatt Edison-Hopkinson machines had an armature resistance of ·0117 ohm and a shunt field resistance of 52·7 ohms. They ran at 400 revolutions per min., and gave out 590 amperes at 410 volts at full load. Their electrical efficiency was 95·9 % at half load, and 97·2 % at full load; their mechanical efficiency 97·7 %, and commercial efficiency 95 % at full load.

A 5 k.w. dynamo may require 330 watts in its magnet coils, and absorb 200 watts in the armature at full load; which is equivalent to an elec. eff. of 90·4 % only.

If we know the output and terminal pressure of a dynamo, and the resistance of its armature and field windings, as in the case of the Edison-Hopkinson machines mentioned above; or if we know the output and the watts lost in the machine, as with the 5 k.w. dynamo just cited, we can calculate the electrical efficiency as follows.

TO CALCULATE THE ELECTRICAL EFFICIENCY OF A DYNAMO, KNOWING ITS RESISTANCE, OR THE WATTS LOST IN IT, AND ITS OUTPUT.

EXAMPLE.—*A series dynamo has an armature resistance of* ·35 *ohm and a field resistance of* ·58 *ohm. At a certain speed it gives a P.D.*

of 230 volts, and a current of 25 amperes. What is its electrical efficiency?

The output $= 230 \times 25 = 5750$ watts. The watts lost in the machine $= C^2R = 25^2 \times (\cdot 35 + \cdot 58) = 625 \times \cdot 93 = 581$. (Chap. **IV.**)

$\therefore$ Total power developed $= 5750 + 581 = 6331$ watts.

$\therefore$ Electrical efficiency $= \frac{5750 \times 100}{6331} = 90 \cdot 8\ \%$.

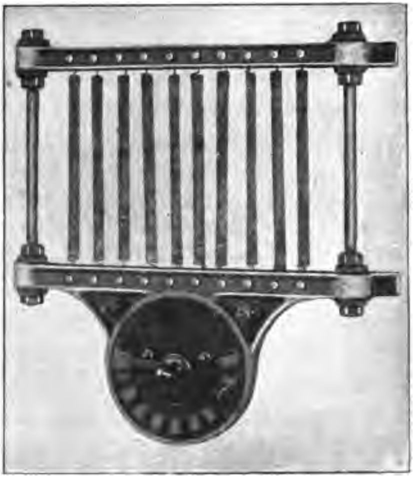

FIG. 12.—Regulator or Rheostat (P. R. Jackson & Co.).

The word *unit* as applied to dynamos is a short expression for kilowatt; thus a 60-unit generator is one giving an output of 60 kilowatts.

*10. REGULATORS.—A compound-wound dynamo will maintain a constant pressure on a distribution circuit supplying say incandescent lamps, provided that the driving speed is kept constant. It is, however, extremely difficult

to maintain a perfectly regular speed; and rather so to get a dynamo with a perfectly flat characteristic, or one which rises evenly, the first being necessary when the "load" is adjacent to the machine, and the second when it is at the end of a feeder main (p. 22).

To provide for the consequent small changes in pressure,

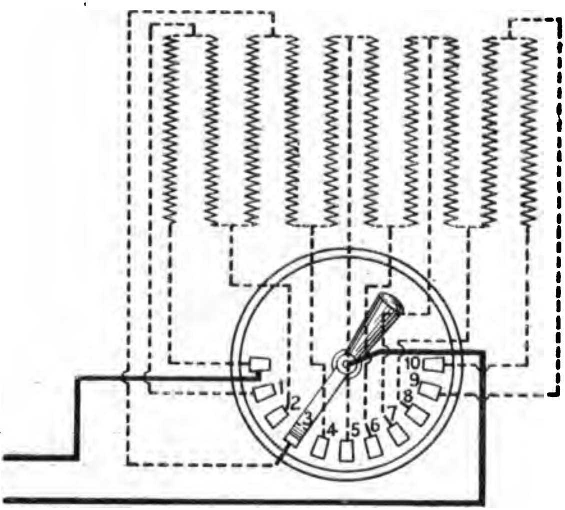

FIG. 13.—Internal Connections of Regulator.

and to enable the pressure to be raised with the load, it is usual to connect *regulators* or *rheostats* in the shunt exciting circuit. These regulators are made in various forms, but generally consist of a number of spirals of platinoid, iron, iron alloy, German silver, or other wire arranged in a fireproof case or frame, and connected with a multiple-contact switch by means of which the amount of resistance

in circuit may be varied. One form of regulator is shown in Fig. 12. In this the spirals of resistance wire are mounted on porcelain insulators fixed on a stout iron frame, the spirals being joined up in series as shown diagrammatically in Fig. 13, the top and bottom junctions of adjacent spirals being connected through asbestos-covered copper wires with the switch contacts. The connecting wires from the top pass down behind the spirals, but are not shown in Fig. 12. When the switch is on

Fig. 14.—22-Point Regulator (Sturtevant Eng. Co.).

contact No. 1, only one spiral is in circuit. In the position shown, three of the spirals are in use; while if it be put round to contact No. 10, the whole of the resistance will be in circuit. This simple type of regulator is suitable for fixing to a wall.

Another form of regulator, in which, as is usual, the resistance wires are completely enclosed in an iron frame, is illustrated in Fig. 14. This is adapted for screwing to the floor, and the switch has 22 "ways" or "points." The front of the frame is ribbed to assist it in dissipating any heat generated in the coils.

Fig. 15 gives a side view of a field rheostat for mounting on the back of a switchboard, as illustrated, the switch lever being operated by a hand-wheel on the front of the board. This regulator has no less than 45 "points." The distribution of the resistance, which is made of fine iron wire, and is embedded in enamel, is shown in Fig. 16.

Fig. 15.—Switchboard Regulator (Ward-Leonard).

The last two "stops," it will be noticed, introduce a great deal of additional resistance into the circuit, this being practically equivalent though preferable to actually breaking the circuit. One terminal of the regulator is joined to the top left-hand stud, and the other to the switch lever, which is omitted from the figure.

Automatic regulators are referred to in § 13.

The method of connecting ordinary or *hand regulators* in circuit depends upon the type of dynamo, but in all cases the object in view is to be able to vary the current in the F.M. exciting coils, without directly influencing the current going out to the supply circuit. The advantages of this arrangement are that the regulating appliance can be

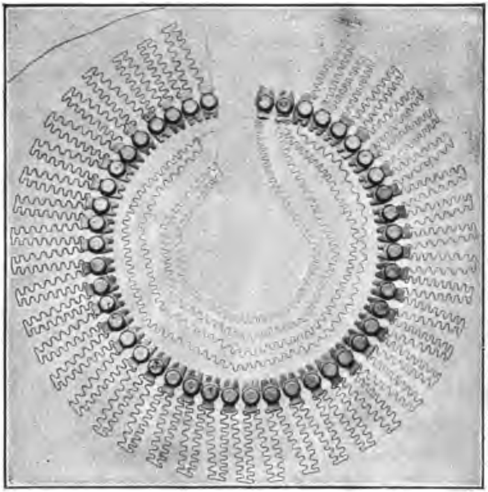

FIG. 16.—Distribution of Resistance Wire in Regulator.

simply and cheaply made, as it is generally only required to carry a small current, and the power taken by the dynamo is reduced in proportion to the supply. If, on the other hand, the regulation were effected by inserting resistances in the main circuit, a large amount of power would be wasted, and the appliance would be bulky and costly, as it would then have to carry the whole current.

*11. SHUNT AND COMPOUND REGULATORS.—In the case of a shunt machine, the rheostat or variable resistance *R* is usually connected in series with the exciting circuit, as shown in Fig. 17. The main terminals of the machine are those marked 1 and 2. Instead of the shunt-winding *Sh* being connected direct to terminal 1 it is brought up to a third terminal, 3. The rheostat *R* is put in between 1 and 3, and this must be capable of carrying the maximum field-current without undue heating. The success of this method of regulation is due to the

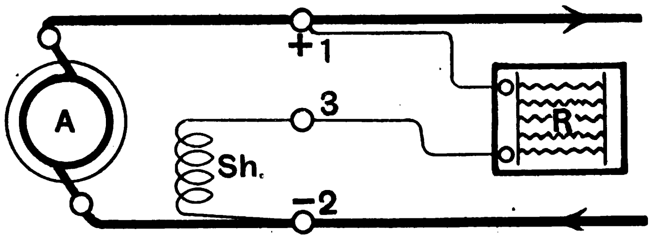

FIG. 17.—Regulator with Shunt Dynamo.

small variation necessary. If the pressure is too high, a very small alteration of the rheostat resistance *R*, so as to reduce the field current, will bring it down to its proper value, and *vice versâ.*

The same principle may be applied to compound-wound machines, as it affords a means of adjusting the proportionality between the shunt and series excitation so as to alter the characteristic as desired. In this case it is not customary to make use of the regulator to correct for any *small* variation, as the compound winding takes care of ordinary changes of load. The connection of the rheostat

in such a case is shown in Fig. 18. Here *Se* and *Sh* are the series and shunt windings respectively, *R* the rheostat, and *1* and *3* the main terminals.

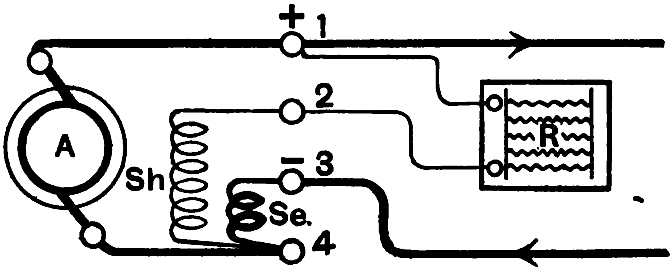

FIG. 18.—Regulator with Compound Dynamo.

*12. SERIES REGULATORS.—In a series or constant-current dynamo, the object of regulation is to vary the pressure at the terminals to suit any variation of the

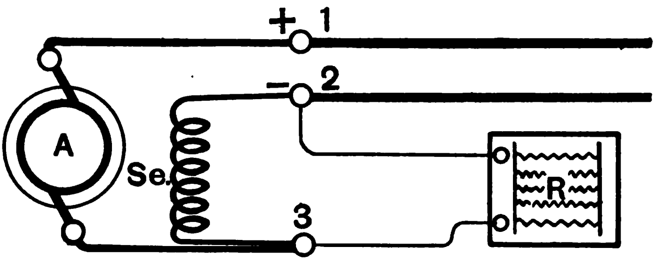

FIG. 19.—Regulator with Series Dynamo.

circuit-resistance. Since the main current flows through the F.M. winding, the regulator cannot be placed in series with these coils, as this would mean that the line current had to be altered when it was desired to make a change in

the excitation. The rheostat must be placed in shunt with the magnet-winding, as shown in Fig. 19. A small portion of the main current then flows through the regulator, and the remainder through the F.M. windings; and the excitation and therefore the E.M.F. of the dynamo can be altered so as to maintain a constant current.

13. AUTOMATIC REGULATORS.—Automatic regulators are those which operate by themselves. Most of these actuate an adjustable resistance, connected as in Figs. 17, 18, or 19, and so vary the pressure at the terminals of the dynamo. In the Thomson-Houston dynamo for arc lighting, and in one or two other special machines which have now dropped out of use, the regulator acted by shifting the brushes.

If, in the case of a dynamo for maintaining a constant current, the main current is passed through a solenoid wound with a few turns of thick wire: or if, with a constant-pressure machine, a solenoid wound with fine wire be connected across the terminals, the pull on a core suspended in the solenoid will vary with changes of current and pressure respectively, and the moving core may be made to actuate the variable resistance. Such devices are little used now, but the Brush-Geipel and the Goolden automatic regulators may be cited as examples of this type. The latter was illustrated and described in an early edition of this work.

14. COUPLING OF DYNAMOS IN SERIES OR IN PARALLEL. —If one dynamo is not enough to supply the demand, and a number of machines are available, two or more of these may be connected so as to give a joint supply to a circuit or system of circuits. We will briefly explain

the chief ways in which parallel and series coupling can be effected with different types of machine.

Series-wound dynamos can be connected in series, or shunt-wound dynamos in parallel, without any special difficulty; but in the first case the current must be the same, and in the second case the pressure. But the pressures added in series (in the first case), and the currents added in parallel (in the second case) may be different; or in other words, different-sized machines may be worked together. Let us take the case of batteries for comparison. Two cells of the same or of different E.M.F. may be coupled in

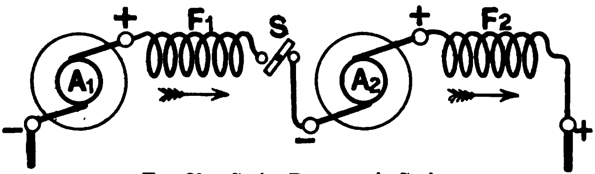

FIG. 20.—Series Dynamos in Series.

series, but the current passing through each will be the same. On the other hand, if cells are to be connected in parallel, their E.M.Fs. must be equal, though one cell may give more current to the circuit than the other. If two dynamos or two batteries of unequal E.M.F. were joined in parallel, the one with the greater E.M.F. would force current through the other.

Fig. 20 represents two series machines connected in series, A_1 and A_2 being the armatures, and F_1 and F_2 the field-coils. Care must be taken that both armatures and field windings are able to carry the maximum current without overheating. The resultant E.M.F. will be the sum

of the individual E.M.Fs. of the two machines. Thus if one machine alone develops an E.M.F. of 1000 volts, and the other 500 volts, when they are joined in series, the total E.M.F. will be 1500 volts. They should be started at the same time, if already connected together in circuit, otherwise the current from the one first started will flow through the other and tend to rotate its armature as a motor in a contrary direction, to the possible detriment of the brushes (§ 108). The best way is to start them first, and afterwards switch them together, a switch for this purpose being

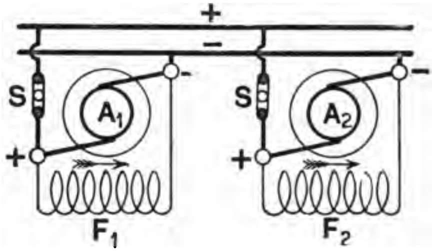

FIG. 21.—Shunt Dynamos in Parallel.

inserted at *S*. If the ordinary circuit switch is near at hand, *S* may be dispensed with.

Fig. 21 shows two shunt machines coupled in parallel, with disconnecting switches *S*, *S*. As before stated, their E.M.Fs. must be equal, but their currents may be different. Thus one may furnish 200 amperes to the circuit, and the other only 100 amperes; the total current then being 300 amperes. The pressure between the mains, however, will be equal to that of either machine. Having started one dynamo and connected it to the circuit, the other must be run up to the proper pressure before switch-

ing it in. If, say, two machines were already connected together to the mains, and one was started before the other, a current would flow through the latter and tend to rotate it as a motor. This rotation, by the way, would be in the same direction as that in which the machine would be driven as a dynamo (§ 108). If the armature were free to run, it would set up a counter E.M.F. and the current flowing through it would be reduced (§ 111): but in most cases the belting or other gearing to the engine would prevent this, and a dangerously heavy current might flow through the armature, and possibly burn it out.

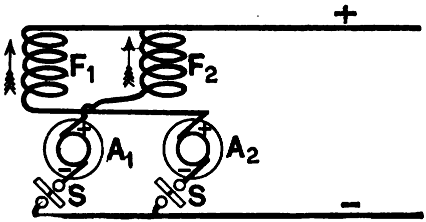

FIG. 22.—Series Dynamos in Parallel.

The coupling of shunt dynamos in parallel is the usual practice adopted in direct-current central station work; and special automatic cut-out switches are used for connecting them to the mains or bus-bars (Chaps. II. and XVII.).

In connecting two series dynamos in parallel, the current taken from the armature of No. 1 should be sent round the fields of No. 2, and the armature current of No. 2 round the fields of No. 1; as shown in Fig. 22. If this were not done, there would be a likelihood of the current from one dynamo reversing the polarity of the other; but,

as will be seen from the figure, this cannot possibly happen under the conditions there given. Besides, any variation in the current in one machine correspondingly alters the field and the current of the other, and the two thus tend to balance each other. The machines must of course be started before being switched in circuit at *S*, *S*, else the current in one may flow through the other and tend to drive its armature in a contrary direction, as was mentioned in the case of coupling series machines in series.

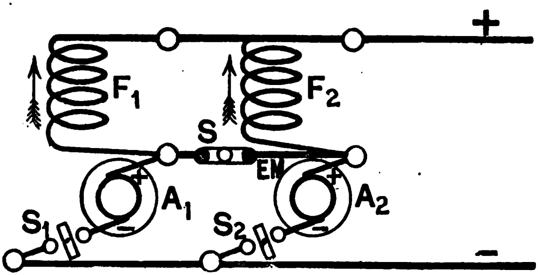

FIG. 23.—Series Dynamos in Parallel.

Another method, which however is not quite so good, inasmuch as the dynamos do not exercise much controlling effect on each other, is shown in Fig. 23. The terminal between the armature and field of No. 1 dynamo is connected with the corresponding terminal of No. 2 by a thick conductor *EM*, which is called the "equalizing main." This prevents any reversal of the fields. The switch *S* in *EM* being closed, suppose No. 1 machine is started first, and then switched in circuit at S_1; part of the current will flow through the field of No. 2 and give it its proper polarity. Then No. 2 can be started and

switched in at S_2. So long as both machines give the same P.D., there will be no current through *EM*, but if one machine drops in pressure, say owing to a slackening of its engine, there will be a P.D. between the ends of *EM*,

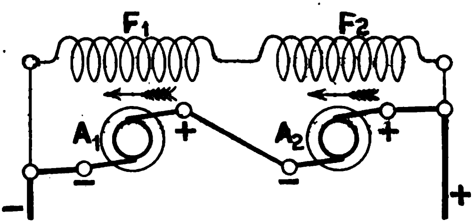

FIG. 24.—Shunt Dynamos in Series.

and current will flow along it to strengthen the field of the weaker dynamo. When only one machine is running, the equalizing main must be disconnected at the switch *S*.

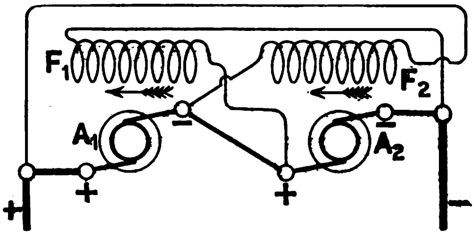

FIG. 25.—Shunt Dynamos in Series.

There are two methods of coupling shunt-wound dynamos in series. In one (Fig. 24) the field coils F_1 and F_2 are connected in series so as to form one long shunt to the circuit terminals, otherwise each machine would tend to reverse the other's polarity. Failing a

special arrangement of switches, which we have not shown in order to simplify the figure, both dynamos should be started simultaneously.

The other method is as illustrated in Fig. 25, the armature of one machine exciting the other's field and *vice versâ.* Although the dynamos tend to balance each other, there is still a slight possibility of a reversal of polarity if one machine suddenly stopped. On this account the first described method is to be preferred.

Compound dynamos may be joined in series as shown in

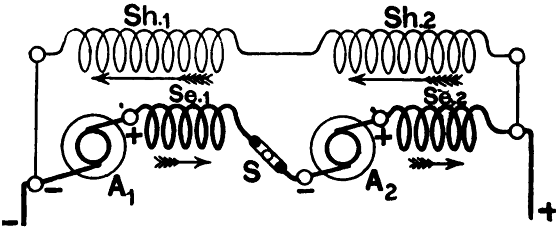

Fig. 26.—Compound Dynamos in Series.

Fig. 26, which should be compared with Figs. 20 and 24. It will be observed that one end of each shunt-coil is disconnected from its machine, the two free ends being joined together to form one long shunt. Reversal of polarity is then rendered impossible. Unless both machines are started simultaneously, the current from the one first started must be prevented from going through the armature of the other, or it will tend to drive it in a contrary direction as a motor, as mentioned at the beginning of this paragraph. To guard against this the switch *S* is kept open until both armatures are running.

The coupling of compound dynamos in parallel presents very little more difficulty than occurs with plain shunt machines, and the remarks made in connection with Fig. 21 apply to this case also. The machines should have a short-circuiting switch *S S* (Fig. 27) across the series windings, and the latter should be cut out at the time of starting or stopping the dynamos, otherwise a reversal of polarity may take place.

It is not often that series dynamos are connected in

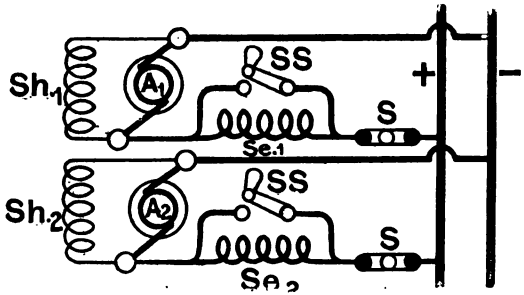

FIG. 27.—Compound Dynamos in Parallel.

parallel, or shunt or compound dynamos in series; though it is interesting to know how this can be done.

The methods of regulating dynamos, as described in §§ 11 and 12, may be applied in any of the above cases relating to coupled machines.

15. CHANGING OF CONNECTIONS, ETC., TO ENABLE A DYNAMO TO BE RUN IN A CONTRARY DIRECTION.—If it is required to run a series machine in the opposite direction to that in which it was originally arranged to turn, without altering the F.M. polarity, the inner end of the field-winding must be changed from one brush to the other.

With a shunt machine, the field connections must be changed over to the opposite terminals.

In a compound machine, whether long or short shunt, the ends of the shunt-winding must be reversed at their terminals, and the connection of the series coil altered as with a plain series machine.

In all three cases, unless the brushes are of the end-on type, their "trail" or slope must be reversed. Their "lead" (§ 116) will also want re-adjusting.

16. Dynamo Design.—The designing of direct-current dynamos involves such electrical questions as form of F.M., size and material of F.M. and armature cores, ampere-turns of excitation on F.M., flux in field, size and number of conductors on armature, armature reactions, etc., and their relation to one another. Besides these, there are numerous mechanical considerations relating to details of construction and fitting. The qualities aimed at are simplicity and strength of design, compactness, efficiency, and economy in manufacture.

In the early days of electric lighting, many machines were designed that were fairly good electrically, but bad mechanically; some being almost impossible of construction. Now-a-days, the difficulty is to improve on existing types.

We shall confine our attention principally to 2-pole dynamos, and the reader is reminded that a good deal has already been said regarding simple points in the construction of F.Ms., armatures, commutators, brush-holders, and brushes, as well as the general arrangement of machines (Chaps. *VIII.* and *IX.*).

The questions which will now be considered will be

mainly electrical ones, such as the connection between the flux from the F.M. through the armature, the speed of rotation of the latter, the number and length of conductors on it, and the E.M.F. generated.

17. CORES OF F.MS. AND ARMATURES. POLEPIECES.—The iron core of a dynamo armature is mainly for the purpose of bridging the gap in the circuit of the F.M. between its polepieces. As the object is to get the greatest possible flux for the conductors to cut through, the core must have small magnetic resistance or reluctance, *i.e.* it must be of good permeability. It must also have as little hysteresis as possible, as its magnetization is constantly being reversed. Armature cores must therefore be of the purest and softest iron, or of very mild steel, these materials having greater permeance and less hysteresis than other grades of iron or steel (Chap. *VI.*).

Field-magnet cores, on the other hand, may be of wrought-iron, cast-iron, or cast-steel, according to circumstances. Where lightness is the first consideration, wrought-iron is used for the whole of the F.M., as the permissible mass of metal in the core being limited, its permeability must be as high as possible. There are, however, two chief drawbacks to the use of wrought-iron for the whole of the F.M. Firstly there is the expense of construction, as no portion can be cast; and secondly there is the liability of the dynamo failing to excite, or having its polarity reversed, owing to the low retentivity of soft wrought-iron.

When the yokes and polepieces are made of cast-iron the cost of construction is much decreased, and the retentivity of the magnet as a whole is increased. Sometimes

every part of the magnet is of cast-iron, but it is generally advisable to have the coil cores of wrought-iron, as the presence of impurities in cast-iron is not always avoidable, and such materially lower its magnetic qualities. Special cast-steel is now much used for field magnets, this material being stronger than cast-iron, and in some cases more permeable even than wrought-iron, while it possesses the necessary retentivity. Much, however, depends on the steel containing a low percentage of carbon in its composition, which value should not exceed 0·25 %.

18. CONNECTION BETWEEN WINDING, FIELD, SPEED, AND E.M.F. OF A DYNAMO.—In Chap. *VIII.* it was stated that the E.M.F. (E) of a dynamo was directly proportional to the total length (L) of active conductor on its armature, to the strength of its field (H), and to the speed of rotation or velocity (V) with which the armature conductors cut the lines of the magnetic field.

Thus:— $$E \propto L \times \mathsf{H} \times V. \qquad \text{(I.)}$$

Starting with this simple statement, it will now be shown how the quantities L, H, and V are to be determined.

V naturally depends principally on mechanical and outside considerations, such as the type of engine to be used, and the method of gearing it to the dynamo (§ 27); and also on the position of the dynamo. For instance, if the machine is to be light and of small size, as for use on ships, trains, etc., it must be driven at a high speed to get the requisite output from it. Generally, of course, slow speeds are preferable, as the wear and tear is less, and the friction losses are reduced.

The quantities L and H depend on numerous consider-

ations as to the size and form of armature and F.M., and it is with these that we are principally concerned.

19. DESIGN OF 2-POLE DYNAMOS.—As a general rule it is best to have large F.Ms. and as strong a field as possible, as this minimizes armature reactions (§ 2), lessens the tendency to sparking, and reduces the number of necessary armature conductors. The magnetic field or flux of a dynamo F.M. depends on its ampere-turns of excitation, and on the permeance of its magnetic circuit, which latter of course includes the armature core. The magnetic circuit should generally be as short, and its cross-section as large as possible; while the two air-gaps between the pole faces and the armature must not be wider than absolutely necessary.

20. DESIGN OF 2-POLE DYNAMOS (*cont.*).—

Instead of L and H and V (§ 18) it is more convenient to speak of the number of active conductors *in series* (N),[1] the total flux (F), and the number of revolutions of the armature per second (n). The formula then becomes:—

$$E \propto N \mathsf{F} n \qquad \text{(II.)}$$

We are here dealing with C.G.S. lines of force (Chap. *VI.*), and the cutting of 1 such line per second generates 1 C.G.S. unit of E.M.F.

But the volt or practical unit of E.M.F. is equivalent to 100,000,000 C.G.S. units; consequently a cutting of

[1] We cannot say "number of turns," as one turn on a drum armature gives two active conductors; whereas one turn on a ring armature gives only one. Sometimes a number of parallel conductors are joined together at each end to the connector and commutator segment respectively; and obviously such would act as a single conductor only.

100,000,000 or 10^8 lines[1] per second is necessary to generate 1 volt.

Thus:— $$E \text{ (in volts)} = \frac{N\,F\,n}{10^8} \qquad \text{(III.)}$$

It will be clear that, in a 2-pole field, every conductor will cut the lines *twice* in each revolution. Also that as the two halves of the armature are in parallel between the brushes, the E.M.F. developed will be only one-half of that given by considering the total number of active conductors on the armature. Hence, for the first reason, it would seem necessary that the number of lines in the field should be multiplied by 2; and for the second that the whole equation should be divided by 2; *i. e.*:—

$$E \text{ (volts)} = \frac{2\,N\,F\,n}{10^8 \times 2} \qquad \text{(IV.)}$$

but this of course is equivalent to the equation as it stands in III.

[1] 100,000,000 may be shortly written 10^8, which means 1 with 8 noughts written after it. Similarly $10^5 = 100{,}000$, and $10^2 = 100$. The small figure is called the *power index*. Sometimes this power index is negative, as 10^{-3}, which signifies $\frac{1}{1000}$. Similarly $10^{-8} = \frac{1}{100{,}000{,}000}$. 55,000,000 may be written shortly 55×10^6: $\cdot 00001 = \frac{1}{100{,}000} = 10^{-5}$: $\cdot 00000103 = \frac{103}{100{,}000{,}000} = 103 \times 10^{-8}$, and may also be written $\cdot 0^5 103$.

A quantity with a negative power index is the reciprocal of the same quantity with a similar but positive index. Thus 10^5 is the reciprocal of 10^{-5}, the first being 100,000 and the second $\frac{1}{100{,}000}$. Any factor in an expression may be transferred from the numerator to the denominator, or *vice versâ*, by altering the sign of its power index.

When the number of lines cut per sec. is considered, we must take into account the number of conductors that do the cutting, as well as the number of lines. Thus 1000 million lines cut by 1 conductor in 1 sec. would generate the same E.M.F. as 10 million lines cut by 100 conductors in 1 sec., viz. 10 volts. If 1 conductor cuts any given field say 50 times in 1 sec., this is equivalent to 50 separate conductors cutting the same field once in 1 sec.

EXAMPLES.—(a.) *The ring armature of a dynamo has* 125 *turns upon it, and is driven at a speed of* 600 *rev. per min. The flux of the* 2*-pole field is* 17,200,000 *lines. What E.M.F. is generated in the armature?*

Using formula III.:—600 rev. per min. is 10 rev. per sec., therefore $n = 10$. $F = 17{,}200{,}000$, and N is 125.

$$\text{Therefore :— } \quad E = \frac{125 \times 17{,}200{,}000 \times 10}{10^8}$$
$$= 215 \text{ volts.}$$

(b.) *In a separately-excited* 2*-pole dynamo, the flux is* 10^7 *lines, and the number of active conductors is* 150. *At what speed must the machine be driven to generate* 108 *volts E.M.F.?*

Let x = required speed. Here $E = 108$, $F = 10^7$, $N = 150$, and $n = x$.

$$\text{Thus :— } \quad 108 = \frac{150 \times 10^7 \times x}{10^8}$$
$$\text{Whence :— } \quad x = \frac{108 \times 10^8}{150 \times 10^7}$$
$$\textit{i. e.} :\text{— } \quad x = \frac{108}{15}$$
$$= 7{\cdot}2 \text{ revs. per sec.}$$
$$= 432 \;\;,, \;\;,, \text{ min.}$$

(c.) *A drum armature in a* 2*-pole field carries* 160 *external conductors, and runs at* 580 *r.p.m. Find the necessary flux through*

the armature to give a P.D. at the terminals of 220 volts on open circuit.

Let x = required flux. Then $\mathbf{F}$ = x, E = 220, N 160, and n = 580 ÷ 60 = 9·7

$$\text{Thus :—} \quad 220 = \frac{160 \times x \times 9{\cdot}7}{10^8}$$

$$\text{and :—} \quad x = \frac{220 \times 10^8}{160 \times 9{\cdot}7}$$

$$= \frac{22{,}000{,}000{,}000}{1552}$$

= about 14,180,000 lines.

(d.) *A ring armature for a 2-pole field, whose flux is 10 million lines, is to run at 720 r.p.m. What number of turns must it have to generate 224 volts?*

Let x = number of turns = N. Then $\mathbf{F} = 10^7$, $n = 12$, and E = 224.

$$224 = \frac{x \times 10^7 \times 12}{10^8}$$

$$\therefore \quad x = \frac{224 \times 10^8}{10^7 \times 12}$$

$$= \frac{224 \times 10}{12}$$

= 187 turns.

It might be convenient to take the *megaline* as equivalent to one million C.G.S. lines, and denote it by the symbol *ml*. Then 15·66 *ml* = 15,660,000 C.G.S. lines, and so on. The unit suggested and used by Kapp is equivalent to 6000 C.G.S. lines: that is to say, 1 *Kapp line* = 6000 C.G.S. lines.

21. E.M.F. OF MULTIPOLAR DYNAMOS.—With 2-pole dynamos, as we have seen—$E = \frac{N\,\mathbf{F}\,n}{10^8}$.

In applying this formula to multipolar machines, we

must take into account the number of pairs of poles, and multiply by that number; F being taken as the flux between any single pair of poles.

For instance, let us suppose that three machines (respectively 2-pole, 4-pole, and 6-pole) have the same *pole strength*, i.e. the same number of lines proceeding from or entering any one pole. Then, assuming the same type of armature winding in each case, the conductors on the armature of the 2-pole machine would in one revolution pass in front of one S and one N pole: while in the 4-pole machine they would pass two S and two N poles, *i.e.* they would cut double the number of lines in one revolution. Similarly, with a 6-pole machine, three times the number of lines would be cut in one revolution.

Formula III. may then be modified as below to enable it to be applied to machines having any number of pairs

$$E = p\,\frac{N\,\mathsf{F}\,n}{10^8} \qquad \text{(IIIA.)}$$

of poles p. For 2-pole machines $p=1$, for 4-pole machines $p = 2$, for 6-pole machines $p = 3$, and so on.

*22. TERMINAL P.D. OF A DYNAMO.—The P.D. at the terminals of a separately-excited dynamo on open circuit is the same as its E.M.F. The E.M.F. and consequently the P.D. at the terminals of a series dynamo on open circuit are practically nothing. With a shunt or compound machine under similar conditions, the terminal P.D. is slightly less than its E.M.F., but may be assumed to be about the same.

When any machine is giving current to the circuit, there is a loss of volts in the armature, which is propor-

tional to its resistance, and to the current being drawn from it. Again, the greater the current taken from the armature, the greater is the weakening of the field due to armature reaction (§ 2). Thus the E.M.F. of a machine, and the difference between this and its P.D., depend upon the load on it.

23. Calculation of F.M. Winding.—In Chap. *VI.* we were given the formula connecting the field intensity, field area, and the flux. Thus the flux F across the air-gaps of a 2-pole dynamo depends upon the intensity of the field H, and on its area s,

$$\text{or:—}\quad \mathsf{F} = \mathsf{H} \times s.$$

As however the field in these air-gaps is not generally of uniform intensity, we must deal at once with F: and this value is clearly directly proportional to the magneto-motive force of the field coils, and inversely proportional to the reluctance of the magnet circuit, including the armature core and air gaps,

$$\textit{i.e.}\ \mathsf{F} = \frac{\text{Magneto-motive force (M.M.F.).}}{\text{Reluctance of magnetic circuit.}} \qquad \text{(V.)}$$

The reluctance and permeance of any magnetic material vary with every change in the flux passing through it; but if we take into account the permeance of the material at the given value of the proposed flux, we can arrive at the corresponding value of the reluctance, for

$$\text{reluctance} = \frac{1}{\text{permeance}} \qquad \text{(Chap. \textit{VI.})}$$

The permeance of any portion of a magnetic circuit is clearly directly proportional to its sectional area s and

permeability μ; and inversely proportional to the length l of that portion.

$$\text{Thus :— permeance} = \frac{s\mu}{l}$$

$$\text{Consequently :— reluctance } (\mathsf{R}') = \frac{l}{s\mu} \qquad \text{(VI.)}$$

Take for example the magnetic circuit of a simple

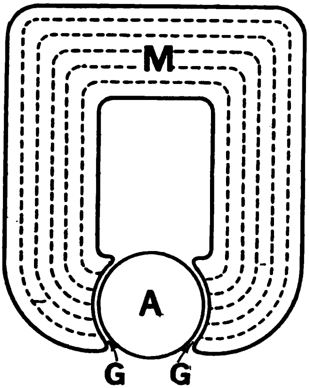

FIG. 28.—Magnetic Circuit of a Dynamo.

2-pole dynamo (Fig. 28), omitting all consideration of magnetic leakage; and suppose, for the sake of simplicity, that the magnet-cores, yoke, and polepieces are all of the same material and cross section. The circuit is made up of four parts :—F.M. core *M*, armature *A*, and two equal air-gaps *GG*. The reluctance of the whole circuit is the sum of the reluctances of its component parts, as they are in series.

Thus :— reluctance of F.M. $= \dfrac{l_M}{s_M \ \mu_M}$

reluctance of armature $= \dfrac{l_A}{s_A \ \mu_A}$

reluctance of air-gaps $= 2 \dfrac{l_G}{s_G}$

the permeability in the last case being unity.

Hence the reluctance of the whole circuit :—

$$= \frac{l_M}{s_M \ \mu_M} + \frac{l_A}{s_A \ \mu_A} + 2 \frac{l_G}{s_G} \qquad \text{(VII.)}$$

The **M.M.F.** of a coil or coils of wire =

$$1{\cdot}257 \ CN \qquad \text{(VIII.)}$$

where *CN* are the ampere-turns (Chap. *VI.*). Hence, as by V. Flux ($\mathbf{F}$) $= \dfrac{\textbf{M.M.F.}}{\text{Reluctance}}$.

Flux in dynamo circuit $= \dfrac{1{\cdot}257 \text{ C.N.}}{\dfrac{l_M}{s_M \ \mu_M} + \dfrac{l_A}{s_A \ \mu_A} + 2 \dfrac{l_G}{s_G}}$ (IX.)

or shortly :—

$$\mathbf{F} = \frac{1{\cdot}257 \ CN}{\mathbf{R}'} \qquad \text{(IXA.)}$$

Formulæ V. and IXA. are useful as giving a sort of Ohm's law for the magnetic circuit; but for reasons that were fully entered into in Chapter *VI.*, such cannot be applied with exactitude, for the reluctance varies with different fluxes, and cannot be directly measured, while allowance has to be made for magnetic leakage.

In practice, the size, form, and material of the F.M. and armature core, and the value of **F**, are generally first fixed

upon; and the problem then is to find the necessary number of ampere-turns to produce that flux. Approximate values of reluctance must be assumed, these being got from permeability curves of samples of the metal to be used in F.M. and armature (Chap. *VI.*).

Thus, supposing we are going to use a flux of F lines, and the cross-section of the F.M. core is y sq. cm.; the induction B will clearly be $\frac{\mathsf{F}}{y}$, and the corresponding value (x) of μ is got from the permeability curve. The reluctance of that part may then be assumed to be

$$\frac{l}{sx}.$$

Now a certain number of lines must be allowed for leakage. At a rough estimate, so much of the total flux of the field of a simple 2-pole dynamo is lost through leakage, that if we want a useful flux F, we must set up a total flux 1·3 F. This factor is called the *coefficient of leakage*, and is generally denoted by the symbol ν.[1]

Its value, of course, varies with different types of machine, but may be taken approximately at the above figure for simple 2-pole forms. Thus if F is the useful flux required through the armature, $\nu\ \mathsf{F}$ is the total flux that must be generated in the magnet cores.

From formula V. it is evident that:—

$$\text{M.M.F.} = \text{flux} \times \text{reluctance.}$$

And by VIII., $1{\cdot}257\ \text{CN} = \mathsf{F} \times \text{reluctance.}$

$$\text{Thus:—Ampere-turns (CN)} = \frac{\mathsf{F} \times \text{reluctance.}}{1{\cdot}257} \qquad \text{(X.)}$$

[1] ν = Greek *Nu.*

Therefore to find the total ampere-turns necessary to produce a given useful flux F through the armature (Fig. 28), we may proceed as follows:—

$$\left.\begin{array}{l}\text{Ampere-turns necessary to give} \\ \nu\mathsf{F} \text{ lines through magnet-core.}\end{array}\right\} = \nu\mathsf{F} \times \frac{l_M}{s_M \ \mu_M} \div 1{\cdot}257$$

$$\left.\begin{array}{l}\text{Ampere-turns necessary to give} \\ \mathsf{F} \text{ lines across air-gaps.}\end{array}\right\} = \mathsf{F} \times 2 \ \frac{l_G}{s_G} \div 1{\cdot}257.$$

$$\left.\begin{array}{l}\text{Ampere-turns necessary to give} \\ \mathsf{F} \text{ lines through armature.}\end{array}\right\} = \mathsf{F} \times \frac{l_A}{s_A \ \mu_A} \div 1{\cdot}257.$$

Thus:—

$$\begin{array}{l}\text{Total ampere-} \\ \text{turns needed}\end{array} = \mathsf{F}\left\{\frac{\nu l_M}{s_M \ \mu_M} + 2 \ \frac{l_G}{s_G} + \frac{l_A}{s_A \ \mu_A}\right\} \div 1{\cdot}257. \quad \text{(XI.)}$$

24. OTHER DYNAMO CALCULATIONS.—It is beyond the scope of this book to deal fully with the calculations involved in the design of dynamos, but one or two examples are here given.[1]

EXAMPLES—(*a.*) ARMATURE RESISTANCE. *What is the resistance of a ring armature containing* 160 *turns of rectangular wire having a cross-section of* 0·19 *in.* × 0·20 *in.? The armature core, without insulation, measures* 14 *ins. in length, and its radial depth is* 2 *ins. The resistance of* 100 *yards of copper rod one sq. in. in cross-section may be taken as* ·0025 *ohm.*

The cross-section of the conductor is 0·19 in. × 0·20 in. = ·038 square inch. Being given the resistance of 100 yards of copper rod of 1 sq. inch section, it follows that the resistance of our armature conductor per 100 yards will be :—

$$\text{R. per 100 yards} : {\cdot}0025 :: 1 : {\cdot}038$$

$$\text{i.e. } R = \frac{{\cdot}0025}{{\cdot}038} = {\cdot}0658\ \omega.$$

Each turn of the armature conductor, counting the outside and

[1] Full information may be got from Prof. Silvanus Thompson's standard works, *Dynamo-Electric Machinery* and *Design of Dynamos.*

inside layers and the two ends, and allowing ·2 in. for each bend, will have a mean length of $14·2+14·2+2·2+2·2=32·8$ ins.: and the total length will be $32·8 \times 160 = 5248$ ins. $= 145·5$ yds. Consequently the *total resistance* x, with all the turns in series, will be :—

$$x = \frac{145·5}{100} \times ·0658, \text{ i. e. } x = ·096\ \omega.$$

When an armature is in place in a machine with its brushes fixed, its resistance may be measured by any of the methods for determining very low resistances (Chap. *VII.*). If x is the resistance measured between the brushes, and the armature is a 2-pole one of the ring or drum type, its total resistance will be $4\ x$. For it must be remembered that the two halves of the armature are in parallel beween the brushes, and that the combined resistance of two equal conductors in parallel is only one-fourth of what it would be were they in series. Thus in the example above ·096 ω is the resistance all round the ring. Measured between the brushes, the resistance would be only one-fourth of this, or ·024 ω.

(*b.*) ARMATURE CONDUCTOR. *The core of a ring armature is* 15 *ins. long,* 12 *ins. in outer diameter, and* 2·5 *ins. in radial thickness. What wire would you use to give* 275 *volts P.D. at its terminals; and what current could be safely drawn from the machine if it is to be driven at a speed of* 1200 *revs. per minute? The* 2-*pole field-magnet is to be shunt wound.*

The first thing is to ascertain the sectional area of iron in the armature core, the section being taken at right angles to the direction of the field. The shape and dimensions of this are given in Fig. 29. If the core were solid, the area would be $2\ r \times l$, where r is the radial thickness and l the length, it being remembered that the lines have two paths across from pole to pole. But, as the core is laminated, the total length of iron is something less than l, allowance having to be made for the varnish, paper, or other insulator placed between the core discs to retard the setting up of eddy currents. We must

therefore multiply l by a factor f, which will reduce it to something less; the space occupied by non-magnetic material being, say, about 13 per cent. of the whole length. Calling a the net sectional area of the core, we have :—

$$a = 2\ r \times l \times f.$$

In the present case $r = 2{\cdot}5''$, $l = 15''$, and f may be taken as ·87. Then :—

$$a = 5 \times 15 \times {\cdot}87,$$
$$= 65 \text{ square inches.}$$

The usual induction in armatures of this type averages about 100,000 lines per square inch, so that the total flux may be taken as :—

$$65 \times 100{,}000 = 6{,}500{,}000 \text{ lines, or } 6{\cdot}5\ ml\ (\S\ 20).$$

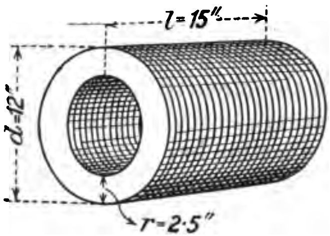

FIG. 29.—Armature Core.

The requisite number of conductors is arrived at as follows :—

Let P = P.D. at terminals of machine.
E = Total volts generated by armature.
e = Volts lost in armature.
F = Magnetic flux through core.
n = no. of revolutions per second.
N = no. of conductors on armature.

Then, using formula III. p. 47 :—

$$E = \frac{N\,\mathsf{F}\,n}{10^8} = (P + e)$$

from which:—

$$N = \frac{E \times 10^8}{F \times n}$$

substituting figures:—

$$N = \frac{275 \times 10^8}{6,500,000 \times 20} = 212 \text{ conductors.}$$

Here we have assumed that 275 volts is the E.M.F. of the machine. Allowance will be made later in order that the dynamo shall give this voltage at its terminals, as desired.

The maximum current that can be taken from an armature is limited by two things, viz. the carrying capacity of the armature conductors, and the cross-magnetization of the armature due to the circulation of current therein, which results in the distortion and weakening of the field (§ 2). This cross-magnetization has to be kept within limits, else there is great sparking at the commutator of the dynamo.

If the number of armature conductors is multiplied by the current flowing through them, the product is termed the *circumflux*, and is denoted by the letter Q. If Ca is the current taken from the armature, $\frac{Ca}{2}$ will be the current in each half of the armature winding, which is divided by the brushes into two parallel circuits, and $\frac{Ca}{2}$ is thus the current in each armature conductor.

Consequently:—

$$Q = \frac{Ca\, N}{2} \qquad \text{(XII.)}$$

The limiting value for Q depends upon the type and

diameter of the armature. Thus if d be the diameter of the armature in centimetres:—

$$Q = 390\,d\begin{pmatrix}\text{for a ring}\\ \text{armature.}\end{pmatrix} = 600\,d\begin{pmatrix}\text{for a drum}\\ \text{armature.}\end{pmatrix} \qquad \text{(XIII.)}$$

These quantities are only reliable when a certain proportion exists between the dimensions of the armature core and the size of the air-gaps (Fig. 28), but we may here take their accuracy as granted.

In the case under consideration:—

$$Q = 390 \times 12 \times 2{\cdot}54 = 11{,}900$$

The diameter being multiplied by 2·54 to bring it to centimetres.

By XII.:—

$$\begin{aligned} \mathrm{Ca\,N} &= 2\,Q \\ &= 23{,}800 \end{aligned}$$

Having already calculated that $\mathrm{N} = 212$, we have:—

$$\mathrm{Ca} = \frac{23{,}800}{212} = 112 \text{ amperes.}$$

$\frac{\mathrm{Ca}}{2}$ or 56 amperes will be the current flowing in each half of the armature, and as it is usual to allow a density of 2000 amperes per sq. in. in armature conductors, we get $56 \div 2000 = {\cdot}0288$ sq. in. as the sectional area of our armature conductor. This is approximately equal to the area of a 7/15 stranded conductor.[1]

It now becomes necessary to revise the value assigned to N, since this was found on the assumption that 275

[1] See the Author's *Electric Wiring Tables.*

volts was the E.M.F. of the machine. We must determine e (the volts lost in the armature), and increase N to compensate for these.

Allowing for connections to commutator, let us assume that the length of each conductor is 44 inches. The total length is consequently $\frac{44 \times 212}{12 \times 3} = 259$ yards.

A 7/15 conductor, or its equivalent, has a resistance of ·852 ω per 1000 yards,[1] so that the total resistance of our armature conductor may be taken as

$$\frac{\cdot 852\ \omega \times 259}{1000} = \cdot 221\ \omega$$

The working resistance of the armature, in which the conductor between the brushes is virtually arranged in two equal portions in parallel, is thus one-fourth of above, or ·0553 ω. The armature current Ca being 112 amperes, the loss of volts therein will be :—

$$\cdot 0553 \times 112 = 6 \text{ volts.}$$

The armature must thus generate $275 + 6 = 281$ volts. Then the revised value for

$$N = \frac{281 \times 10^8}{6{,}500{,}000 \times 20} = 216 \text{ conductors.}$$

The revised value for $Ca = \frac{23{,}800}{216} = 110$ amps., and the cross-sectional area of $\text{wire} = \frac{55}{2000} = \cdot 0275$ sq. in. The nearest size to this, however, is still 7/15.

*25. HEATING OF DYNAMOS.—All dynamos in working

[1] See the Author's *Electric Wiring Tables.*

become more or less heated, this being the necessary consequence of the continuous flow of current in the coils, and the setting up of eddy currents and the effects of hysteresis in the armature core. There is a limit to the degree of heating that can be permitted, and in designing machines attention has to be given to their ventilation, so that whatever heat is generated may be dissipated as much as possible. The overheating of dynamos is bad for three chief reasons. It increases the resistance of the armature and magnet windings, and so leads to a greater loss of power therein; it is harmful to the insulation; and lastly, the framework and shaft of the armature may expand and cause trouble in various ways.

The overheating of the armature is more difficult to guard against than that of the field-coils. Efficient lamination (Chap. *VIII.*) overcomes eddy-current heating, and hysteresis (Chap. *VI.*) is lessened by employing a good grade of iron; while the arrangement and proportioning of the conductors must be carefully seen to. Sometimes one coil will persistently get overheated, even when no current is being taken from the machine. One cause for this would be the short-circuiting of the coil through the armature core, owing to defective insulation.

*26. Faults in Dynamos.—The faults which may crop up in dynamos are so many that it is difficult to treat of them briefly, hence the enumeration of the chief of them must suffice. These may be set down as follows :—

(*a.*) Failure to start generating owing to film of oil between brushes and commutator.

(*b.*) Brushes making bad contact. This often occurs when, in badly-designed machines, the brush-holder bars

are fixed to the rocker through round instead of square bushes and holes.

(*c.*) Flats in commutator. Due to the wearing away of one or more segments more rapidly than the rest, and leading to momentary disconnections of the circuit and consequent sparking.

(*d.*) Breakage or loosening of connections.

(*e.*) Short circuits or leakage in armature or field windings.

(*f.*) Overheating or burning-up of armature or F.M. coils.

(*g.*) Loss of starting field, due to too soft iron in F.M.

(*h.*) Reversal of polarity.

(*i.*) Leakage of current across rocker.

(*j.*) "Hunting," or unsteadiness of E.M.F. Due to working on unstable part of characteristic curve.

(*k.*) Breakage of regulator resistance coils.

(*l.*) Hot bearings, owing to ropes or belt being too tight.

(*m.*) Unsteady driving owing to ropes or belt being too loose.

27. METHODS OF DRIVING DYNAMOS.—There are four methods of gearing a dynamo to the engine or other motor which drives it. These may be classified as follows:—

(*a.*) Direct driving.
(*b.*) Belt „
(*c.*) Rope „
(*d.*) Friction „

In direct driving, the armature shaft is coupled direct to the crank-shaft of the engine. This method is much employed with generators for use in central stations, and in ship work, etc.: and is the best with high-speed engines.

Examples of direct-driven dynamos are given in Figs. *199*, *214*, *219*, and *224*, and it will be observed that in the first-mentioned a flywheel is specially interposed to give steadiness in running. In Fig. *214* the dynamo is driven by a turbine, and in Fig. *224* by a gas engine.

In rope driving, the driving-wheel of the engine and the pulley of the dynamo are grooved to receive a number of ropes. There is less slipping, and consequently less loss of power, with ropes than with a band or belt; and, moreover, the running is not stopped by the breakage of one or two of the ropes, which may be repaired at leisure. If a belt breaks, considerable delay often ensues, unless a spare one is at hand. With leather belting it is best to place the flesh side on the pulley, the belt then lasting longer.

Examples of pulleys grooved for rope-driving may be seen in Figs. *213* and *222*. All the other machines illustrated in Chap. *IX*. are arranged for belt or band driving, which is too well known to need description.

In friction driving, the engine and dynamo pulleys are brought to bear on one another, so that the one drives the other in consequence of the friction between them. This method is very little employed, but we have a domestic example of it in the driving of the spool-winder on a sewing-machine.

The power transmitted by a belt is proportional to its speed, multiplied by the difference in tension between its driving and slack sides. In other words, the greater the tightness of a belt on its driving side as compared with its slackness on the other side, the greater will be the power transmitted at a given speed. If a belt is too tight, extra power will be lost in moving it; while if it is

too loose, there will be slipping. In either case, its speed, as well as the difference in tension between its two sides, will be reduced. So also then will be the power transmitted.

If W is the width of a belt in inches, and V its velocity of travel in feet per minute, the horse-power transmitted will be:—

$$\text{H.P.} = \frac{WV}{K}. \quad \text{Hence } W = K\frac{\text{H.P.}}{V}.$$

K is a constant depending on the character of the belt. For single belting, K varies from 1000 to 800; while for double belting, its value is about 500.

28. HORSE-POWER.—Whether horse-power be termed mechanical or electrical, it is still one and the same thing; namely, an expression signifying a certain rate of doing work, the prefix "electrical" merely indicating that it is used in connection with electrical quantities (Chap. *I.*).

It used to be the custom to speak of the *nominal H.P.* of engines, but this term was vague, and so has dropped out of use. When an engine was said to be of so many *nominal H.P.*, it meant nothing more than that the engine was supposed to be able to yield about that amount of power. The actual power developed was generally found to be considerably less than its rated nominal value. The *indicated H.P.* is the *calculated horse-power* as indirectly determined during the working of the engine; while the *effective or brake H.P.* (B.H.P.) is that actually given out by the crank-shaft, and measured by a dynamometer (§ 128). The effective H.P. is slightly less than the indicated H.P., the difference being absorbed by the engine in moving itself.

CHAPTER X.—QUESTIONS.

In answering these questions, give sketches wherever possible.

1. One coil of a drum armature gets very hot when the machine is running unloaded. What is the cause, and what is the cure? [Ord. 1898.]

2. Draw the kind of characteristic curve which it is necessary that a series-wound dynamo should have if it is to be used for lighting a number of arc lamps arranged in series. Explain the reason why the characteristic should be of the shape shown by you. [Ord. 1892.]

3. What kind of dynamo is the best for use for charging accumulators, and why? [Ord. 1898.]

4. Distinguish between indicated *H.P.*, brake *H.P.*, effective *H.P.*, nominal *H.P.*, and electrical *H.P.* An engine coupled direct to a dynamo is indicating 100 *H.P.*, what would you expect the values of the quantities to be? How many amperes would you expect to get at 100 volts? [Ord. 1891.]

5. Describe a simple shunt dynamo, and show how the electromotive force of such a machine can be regulated. [Ord. 1891.]

6. How could the slight up-and-down motion of the core of a solenoid carrying a varying current be arranged to alter the resistance in a rheostat circuit, as briefly referred to in § 13?

7. What is the difference (*a*) in connections, (*b*) in construction, between a shunt-wound and a series-wound dynamo? Why are arc-lighting machines not generally shunt wound? [Ord. 1896.]

8. Show by means of sketches the methods used for connecting compound-wound dynamos in parallel. [Ord. 1897.]

9. Give sketches showing the way in which (*a*) two shunt dynamos, (*b*) two compound-wound dynamos should be connected so as to work in parallel, and explain your object in connecting them as shown. [Ord. 1901.]

10. Sketch diagrams of connections you would employ to do the following:—

(*a*) Couple two equal series dynamos in parallel.

(*b*) Couple two equal shunt dynamos in series. [Ord. 1893.]

11. Why is it dangerous to lift the brushes of a shunt-wound dynamo when shutting down? State what would occur if you were to lift the brushes of a running shunt-wound dynamo (*a*) while a fair load of lamps are being supplied; (*b*) when no current is being supplied to the external circuit. [Ord. 1896.]

12. Explain why it is generally found impossible to do any of the following things :—
(*a*) Charge a battery from a plain series dynamo ;
(*b*) Couple two plain series dynamos in parallel ;
(*c*) Couple two plain shunt dynamos in series ;
(*d*) Operate several ordinary electric bells in series. [Ord. 1892.]

13. How should a dynamo be wound to give constant pressure with varying load at a distance from the machine ? [Ord. 1897.]

14. What are the advantages and drawbacks of cast-steel for dynamo magnets ? What is the best cast-steel that has been made up to the present time for this purpose ? [Ord. 1897.]

15. A drum armature in a 2-pole field contains 150 external conductors, it runs at 550 revolutions per minute. Find the total flux passing through the armature which is required to produce an electromotive force of 115 volts on open circuit. [Ord. 1893.]

16. Calculate the resistance of a gramme armature wound with 144 turns of rectangular wire $0{\cdot}2 \times 0{\cdot}21$ in., length of armature core without insulation 12 ins., radial depth 2·5 ins. The resistance of 100 yds. of copper rod, one square inch in cross section, is 0·0025 ohm. How would you measure the resistance of such an armature ? [Ord. 1898.]

17. A gramme armature, intended for a 2-pole field, has 120 turns of conductor wound upon it. Give the total flux required through armature core if an electromotive force of 100 volts is to be induced at a speed of 1000 revolutions per minute. [Ord. 1894.]

18. With several direct-current dynamos running in parallel, how would you determine if one was running as a motor ? [Ord. 1898.]

19. What difficulties are likely to occur in charging batteries with a compound-wound machine, and what precautions would you take to avoid them ? [Ord. 1898.]

20. Given a ring armature 10 ins. long, 10 ins. diameter, 1 in. radial thickness of iron ; what wire would you use to give 110 volts, and what current would be suitable ? Speed, 1000 revolutions per minute. [Ord. 1895.]

*21. A shunt dynamo, after being rewound, is run at full speed, but fails to excite its field magnets. What are the various possible causes, and how would you ascertain to which one the fault in the particular case was due ? [Prel. 1899.]

*22. You have a shunt dynamo which is arranged to run in a counter clock-wise direction : what changes would you have to make if the dynamo were required to be run in the opposite direction ? [Prel. 1900.]

23. How does the current in the armature bars under the pole

face in a continuous current dynamo affect the field distribution in the air-gap? How does varying the position of the plane of commutation in the interpolar space with a given load affect the field excitation required for a constant voltage with constant speed? [Ord. 1900.]

24. Name the several causes of waste of energy in a continuous current dynamo machine, and state what devices are necessary, and what precautions should be taken to ensure these being a minimum in any given design. [Ord. 1902.]

25. You have to design a dynamo to give 100 K.w. at 500 volts. State how you would proceed in order to determine the principal dimensions of the armature. Give an example and obtain a first approximation of the dimensions. [Ord. 1902.]

26. Is the flesh side or the hair side of a leather belt run against the pulley of a dynamo? Give reasons. Also state what advantages there are in rope driving over belt driving. [Ord. 1896.]

27. A dynamo takes 98 horse-power to drive it, and runs at 500 revolutions per minute. If it is driven by a belt, and the pulley is 24 ins. in diameter, what will be the difference in tension between the driving and the slack sides of the belt? [Ord. 1902.]

28. A rectangular frame is wound with 100 turns of wire, the average area enclosed by the turns of wire is 500 sq. cms., and the frame is revolved at 1000 revolutions per minute about an axis bisecting the frame, and lying in the plane of the coils in an uniform magnetic field of 750 C.G.S. units, the axis of rotation being at right angles to the direction of the field. What will be the value of the alternating E.M.F. generated? [Ord. 1903.]

29. Discuss the merits and demerits of "resistance" commutation and "E.M.F." commutation in D.C. dynamos, and point out the conditions under which one or the other is to be preferred. [Ord. 1903.]

30. If in Question 28 all the conditions remain the same, but instead of the 100 turns of wire being in one or parallel planes they are distributed around the surface of a cylinder of non-magnetic and non-conducting material (to form a drum or barrel winding), and provided with a commutator sector at each turn, and brushes as in a dynamo, what will be the steady E.M.F. generated, neglecting any consequences that might result from some coils being short circuited at the brushes? [Ord. 1903.]

CHAPTER XI.

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.); and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

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*29. INTRODUCTION.—In this chapter we are concerned with alternating currents. To explain the action of such

in the light of any of the advanced theories would be extremely difficult, if not impossible, in an elementary work like this. Hence, it becomes necessary to adopt the same simple theory as is used in Chaps. *II.* and *III.* in the first volume of this work, and is more fully explained in the Author's *First Book of Electricity and Magnetism.*

*30. ALTERNATING CURRENT.—The simplest kind of current is that derived from a battery. This is a steady direct current, and its principal properties have already been dealt with in Chaps. *II.* and *III.* A well-designed direct-current dynamo gives a current which is very nearly similar in its effects to that of a battery; and for practical purposes, the laws which apply to the current from a battery may be applied equally well to that from a dynamo, or from a rectifier (Chap. XVI.).

If a *reversing switch R*,[1] inserted in the circuit of a battery or direct-current dynamo, as shown in Fig. 30, be

[1] The construction and action of this form of reversing switch are as follows:—On an insulating base, *e*, pivoted at *p*, and provided with a handle, *h*, are mounted the U-shaped piece of metal, + +, and the straight piece, —, to which the + and — poles of the battery are respectively connected. When the switch-handle is in the position shown, the metal tongues, *TT'*, connected with the extremities of the outer circuit, *C*, rest on + +, and no current flows from the battery. If the switch-handle be moved to the right, the right-hand leg of the U-piece remains in contact with *T'*, and the straight piece touches *T*, a current consequently flowing round *C* in a counter-clockwise direction. If the switch-handle be moved to the left, the left-hand leg of the U-piece is in contact with *T*, and the straight piece with *T'*, and a current flows round *C* in a clockwise direction. Thus, if *h* be constantly worked to and fro, an alternating current will be set up in *C*. The actual apparatus is shown in Fig. 30A, where it will be noticed that the connection of the battery is reversed.

operated at regular intervals, alternating E.M.F's. will be *impressed* on the outer circuit *C*, and an alternating current will be set up therein, as conveniently represented by the double-headed arrows ⟷ ⟷.

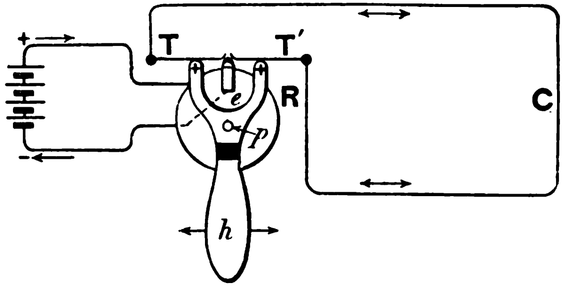

FIG. 30.—Battery and Reversing Switch for setting up an Alternating Current.

Supposing the circuit *C* had no inductance or other disturbing effect, the current or rate of flow of electricity in

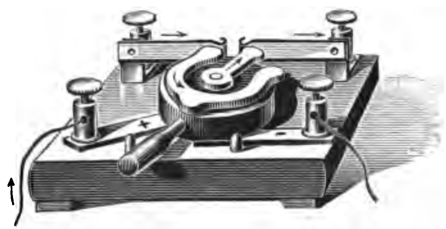

FIG. 30A.—Reversing Switch (J. J. Griffin & Sons).

it would always be the same, but would be reversed in direction at regular intervals, as shown by the "curve" in Fig. 31.

The explanation of this curve is as follows:—Time is

represented along the horizontal line (say, in one-second intervals), starting from the left. Current in one direction is shown by vertical distances above this line, and current in the other direction by vertical distances below it. It is usual to style currents in one direction + (positive), and those in the opposite direction – (negative); but these terms are confusing to the beginner, who would probably assume that a "+ current" was different in its properties from a "– current." We shall therefore refer to them as right- and left-hand currents respectively, these terms well

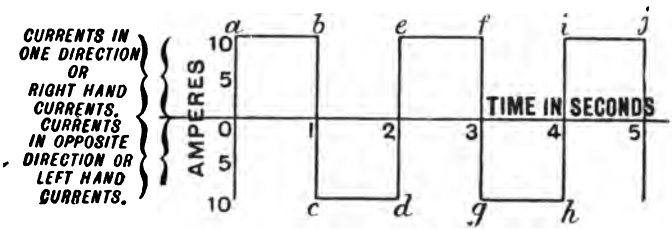

FIG. 31.—Curve of an Imaginary Alternating Current.

conveying the idea that they flow in opposite directions round the circuit. Suppose at the time of commencing the curve, a "right-hand current" was flowing, and that its value was 10 amperes, and suppose also that the direction was reversed every second. Our curve would then start at the point *a*, and would run in a horizontal direction for 1 second—*i. e.* from *a* to *b*—when it would suddenly drop to *c*, the current having been reversed: the "left-hand current," *c d*, would continue for 1 second, as shown, and would then immediately change to the "right-hand current," *e f*. During the fourth second the current would be

"left-handed," *g h*, during the fifth second "right-handed," *i j*, and so on.

The above is a purely imaginary condition of things, however, for a current cannot really change suddenly from one direction to another at its full value; but it is useful, as it gives the student a preliminary idea of an alternating current.

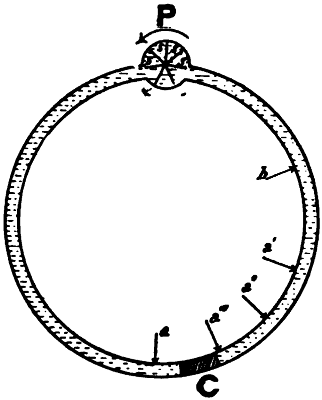

Fig. 32.—Hydraulic Analogue to illustrate an Alternating Current.

*31. Alternating Current (*cont.*).—In Chaps. *II.* and *III.* a steady direct current was likened to a steady flow of water in one direction through a pipe. An alternating current may then be compared with the movement of water in the pipe when the direction of flow is changed more or less rapidly. Fig. 32 shows a pipe bent round so as to form a complete circuit, which includes a pump, *P*; the whole being filled with water. The water stands for electricity, the pipe for the conductor, and *P* for the dynamo

or alternator—according to its method of working. *P* is represented as a kind of small water-wheel, actuated by a pulley or handle outside. If *P* be rotated continuously in one direction, its action is analogous to that of a battery or direct-current dynamo, the water in the pipe (electricity in the conductor) being set flowing in one direction. If *P* rotate first in one direction and then in the other, at regular intervals, it represents the action of an alternator, for there will be a flow of water in the pipe (electricity in the conductor) first in one direction and then in the other. Now electricity—like water—may, for the purposes of this argument, be assumed to be incompressible; so that with a given flow (current), the number of pints of water or coulombs of electricity passing any point, *a*, in the pipe or circuit, is the same as the number passing any point, *b*. Thus, let the shaded part, *C*, represent one pint of water or one coulomb of electricity. When *C* moves in either direction, all the other units of water or electricity in front or behind it, *i. e.* all round the circuit, move at exactly the same rate, irrespectively of the size of the pipe or conductor, which may vary at different parts of the circuit. In other words, the flow of electricity, in coulombs per second (amperes), is the same at all parts of a closed series circuit.[1] When the circuit is not of this description, *i. e.* when it has branches, the current may vary in different parts.

Referring still to Fig. 32, let us consider the action of alternating flow at different *frequencies*—*i. e.* at different rates of alternation (§ 43). The faster *P* works, the greater its water-motive force, and the more rapid will be the flow

[1] Provided it has negligible capacity (§§ 33, 34, etc.).

with a given length and size of pipe (circuit conductor); it being presumed that there is very little waste of energy in the useless carrying round of water in the spaces *s s s s*. Now this water-motive force is clearly analogous to the electro-motive force of an alternator. The frequency of the flow (of water or electricity) does not depend on the value of water-motive or electro-motive force, but on the rate at which the latter change their direction. Thus, if *P* rotate in the direction of the top arrow for half a minute, and then in the direction of the dotted arrow for half a minute, the current will change its direction twice a minute. Now, with a given length and size of pipe (circuit conductor), any particular pint or coulomb, *C*, may make 10, 20, 30, or more "laps" (journeys round the circuit) before the reversal of flow takes place. If the direction of flow be changed at lesser intervals, *i. e.* if the frequency be increased, our pint or coulomb may succeed in making only two or three journeys round in one direction before the reversal of flow occurs. It is thus conceivable that, with a high frequency, one unit of water or electricity may traverse only a part of the circuit (say, from *a* to *b*) before it has to turn back, and that the greater the frequency the less the distance actually travelled over. Thus this path may decrease, as the frequency increases, to a–a', a–a'', or a–a''', it being remembered that there is a similar movement in the other parts of the circuit.

The motion of water or electricity in the circuit depicted in Fig. 32 may thus, when the water or electro-motive force has medium frequency, be compared with that of the balance-wheel of a watch. The current in a given circuit may consequently be supposed to be proportional to the

distance traversed at each alternation by any given coulomb, *C*, multiplied by the number of alternations per second: so that if the current be kept constant, when the frequency is doubled, the path traversed by any given coulomb will be halved, and *vice versâ*. It will be remembered that current is defined as the number of coulombs passing any given point in a circuit per second; and in the case of alternating current we consider the actual number of coulombs passing by, irrespective of their direction of flow.

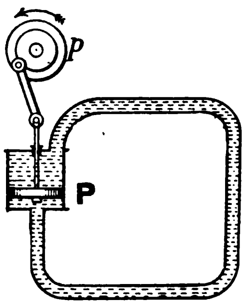

FIG. 33.—Hydraulic Analogue to illustrate an Alternating Current.

Thus, with a very high frequency, it is conceivable that the coulomb *C* (Fig. 32) will merely oscillate in front of the point a''', the number of times it passes this point in one second being a measure of the current.

The greater the frequency, the sharper the to-and-fro movement of electricity; and the comparatively non-dangerous character of extremely high frequency currents, such as are used in etheric telegraphy and other work, may be roughly accounted for by supposing that the electricity in the circuit moves over so minute a path, that

the current is indefinitely small, certain retarding effects increasing with the frequency (§§ 48, 49, 54, and 55).

The hydraulic analogue of an alternating-current circuit is often illustrated as in Fig. 33; the pulley, *p*, representing the rotating part of the alternator; the force of the pump piston, *P*, the electro-motive force; and the up-and-down movement of the piston, the reversals in the direction of the electro-motive force. Good as this analogy is in some respects, it is rather a faulty one, inasmuch as there is no actual passage of water through the pump; and the student might from this infer that there was no passage of electricity through the alternator. But we assume that the electricity flows through the alternator, or dynamo, or battery, just as it does through the other parts of the circuit.

An alternating current might be described as a "continual oscillation" of electricity in the circuit, just as the movement of the balance-wheel of a watch is a "continual oscillation." It must be borne in mind, however, that the use of the term "electrical oscillation" is applied to the movement of electricity when a condenser is discharged, a rapid to-and-fro movement *in an incomplete circuit*, which dies away to nothing. This movement is similar to that of the prong of a tuning-fork, or of one end of a compass-needle coming to rest in a strong magnetic field. The term oscillation should therefore be confined to the case of condensers, to prevent confusion.

*32. ALTERNATING CURRENT (*cont.*).—From what was said in Chap. *IV.*, it should be clear that it is impossible suddenly to start a current at its full value, and equally impossible to stop it suddenly; because of the effects of

inductance or self-induction, etc., the current taking time to "grow" and time to die away. It is thus even more out of the question suddenly to *reverse* a current in a circuit.

Although it is possible to arrange a simple circuit or to wind a coil so that it shall have little or no inductance, as shown in Fig. 34, where each half of the circuit or coil neutralizes the other's magnetic effect; the conductor will still have *capacity* (Chap. *II.*), and this also exercises a disturbing effect on the current. Moreover, a coil such as that shown in Fig. 34 would be useless for solenoids or electro-

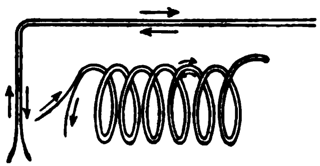

FIG. 34.—Non-Inductive Winding.

magnets, as it would have no magnetic field. It therefore follows that every working circuit exercises more or less disturbing effect, and also that, in the case of an alternating current, this disturbing effect is continuous. Consequently, the "curve" in Fig. 31 does not represent a real alternating current, for such not only varies in direction, but is also constantly varying in strength. With a given circuit, the changes in direction and strength take place at regular intervals, and an alternating current is thus often called a *periodic, harmonic,* or *wave current.* In fact, the curve of a real alternating current is a series of waves, which may be roughly likened to those set up in a rope which is fixed at

one end, while its other end is rapidly moved up and down (Figs. 59, 62, and 64).

There are, however, different kinds of alternating current. That with which we are mainly concerned in this chapter may be termed a *simple alternating*, or *single phase*, or *monophase current*, to distinguish it from *polyphase currents* (§§ 61, 65, 139, etc.).

The simplest case in which an alternating current is set up is when two Bell telephones are used as transmitter and receiver respectively. The iron plate or diaphragm of the telephone used as transmitter, is caused by the voice to perform motions to and fro in front of a magnet, on the end of which a coil of wire is placed. The changes in the strength of field caused by the motions of the iron disk, induce E.M.Fs. in the coil of wire; and as these motions are to and fro, the field is alternately strengthened and weakened, the result of the movement of its lines being an alternating E.M.F. in the coil, which is cut by those lines. As the transmitter is in this case connected to an exactly similar telephone, by a couple of wires forming the circuit, a current alternates in the circuit and coils of both instruments. The magnet of the second telephone (or receiver) being correspondingly strengthened and weakened, its diaphragm is caused to perform movements of a similar character to those of the transmitter diaphragm, and it sets up sound waves in the air in front of it. The transmitter and receiver thus really act as a miniature alternating-current dynamo and motor respectively.

The magneto-machine and bell so much used in telephone and other work afford another example. The

magneto-machine (sometimes called the "ringer" or "generator") is a simple form of alternating-current dynamo, the alternating current being induced by the rotation of a coil of wire in a two-pole magnetic field (§ 42): while the magneto bell may be likened to an alternating-current motor, for its hammer will only move continuously when an alternating current is passed through its coils (Chap. *V*.).

33. Capacity in Alternating-Current Circuits.—One very important difference between the action of

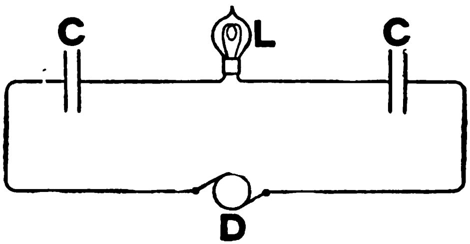

Fig. 35.—Direct-Current Circuit with Condensers.

direct and alternating currents is shown by the experiments illustrated in Figs. 35 and 36. Here two circuits are depicted, each containing a source of E.M.F., a glow-lamp *L*, and two condensers *C*, *C*; but in the first the E.M.F. is due to a direct-current dynamo *D*, and in the second to an alternator *A*. Now, in Fig. 34 it is clear that no current can flow through the lamp, even if one of the condensers be removed, for each of the latter interposes a break in the continuity of the circuit. In Fig. 35, on the other hand, if the condensers are suitable in capacity, the lamp *L* will light up. At first sight this result seems

most inexplicable; but when we consider the action of the condenser,[1] and the fact that the alternator is keeping up a constant surging of electricity backwards and forwards between the plates *a* and *b*, it becomes evident that there must also be a corresponding alternating flow of electricity in the lamp circuit, between the plates *c* and *d*. The results would be precisely the same if one condenser only were employed in each experiment; but the use of two makes the effect in the latter case (Fig. 36) all the more remarkable.

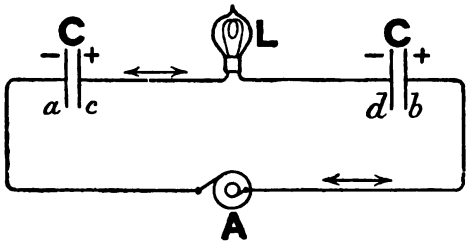

FIG. 36.—Alternating-Current Circuit with Condensers.

It will be noticed that in the experiments above described the capacity is in series with the circuit, *i. e.* there is no continuous conducting path. This state of things effectually prevents the continual flow of a direct current, but does not stop the "action" of an alternating one.

A fuller explanation of the second experiment (Fig. 36) is as follows. Before the alternator is working, the whole circuit may be assumed to be filled with electricity evenly

[1] See the Author's *First Book of Electricity and Magnetism*, Second Edition, § 166.

distributed, and at zero potential or pressure. Now suppose the alternator to work. During the first alternation, *i. e.* while its E.M.F. is in one direction (§ 43), it pumps electricity through itself from *a* to *b*, causing a P.D. between *a* and *b* about equal to its own E.M.F. *b* is consequently + ly. electrified and *a* – ly. electrified, as indicated by the signs + and –. Influence (electrostatic induction) now takes place across the condenser dielectrics, causing a rush of electricity through the lamp from right to left, so that *c* is + and *d* –. During the second alternation, that is when the reversal of the alternator E.M.F. occurs, electricity is pumped from *b* to *a* through the alternator, so that *a* becomes + and *b* –; a rush consequently takes place at the same time from *c* to *d*, *c* becoming – and *d* +, and so on. Thus the reversal and flow of electricity in the alternator circuit causes a corresponding reversal and flow in the lamp circuit.

It has been stated that the same results would have been obtained with one condenser only in circuit. This will be understood from what follows. In Fig. 37, *A* is an alternator, with two wires joined to its terminals; one of the wires being severed, and a lamp, *L*, inserted. The ends of the wires approach very closely, as at *a* and *b*, but are not in contact, a sheet of glass or other dielectric, *d*, being interposed to prevent sparking across. The alternator circuit is consequently not complete. Now the ends of the wires *a* and *b*, and the dielectric *d*, virtually form a condenser of extremely small capacity, and the alternator pumps electricity backwards and forwards between *a* and *b*. But in this case very little electricity passes at each reversal of the E.M.F., owing to the small capacity

of the ends of the circuit; and an ordinary lamp will consequently show no indication of a current. The wires are supposed to be suspended in mid air, and not running side by side or near other bodies, as we wish to consider the circuit as only having appreciable capacity at its ends.

When the alternator is pumping in one direction, say from *a* to *b*, a quantity of electricity will pass sufficient to make the P.D. between *a* and *b* equal to the E.M.F. of the alternator; or, in other words, the condenser *a b* will be charged to the potential of the alternator. Now, the

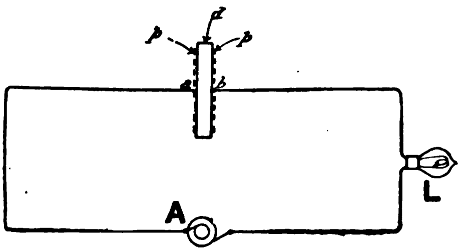

FIG. 37.—Action of Condenser.

smaller the capacity of a condenser, the less is the displacement of electricity necessary to raise the P.D. between its coatings to a given amount. In the present case, because of the extremely small capacity of the ends of the circuit, only a very minute quantity of electricity will pass from *a* to *b*. When the alternator reverses its E.M.F., another small quantity of electricity will be pumped from *b* to *a*; and so on, backwards and forwards with every alternation of the E.M.F.

By putting metal plates on each side of the dielectric, *d*, as shown by the dotted lines *p, p*, the capacity of the

adjacent ends of the circuit (*i.e.* of the condenser) will be greatly increased, and a much greater quantity of electricity will pass to and fro through the lamp. But the current will still be insufficient to light it with a simple two-plate condenser such as this, unless of very unwieldy dimensions, or unless an enormously high E.M.F. be employed. It will be seen, however, that by using a large or multiple-plate condenser of sufficient capacity, an ordinary E.M.F. will cause enough electricity to pass to and fro to light a lamp, or, if need be, a number of lamps.

It has been explained how what is practically an alternating current can be kept up all round the circuit, even if one or two condensers be inserted therein (Figs. 36 and 37); and the reader should now be able to understand that the fanciful arrangement of things depicted in Fig. 38 is possible; any number of lamps, *L*, and condensers, *C*, being joined consecutively in the circuit of an alternator, *A*; the lamps burning brilliantly if the condensers are of sufficient capacity, and the E.M.F. high enough.

As will be presently pointed out, every electric circuit possesses more or less capacity, owing to the proximity of the conductors to each other and to the Earth. Whether capacity can be extensively made use of in ordinary methods of alternating-current electricity supply, is as yet an open question. Mr. James Swinburne has maintained that it can, and has constructed tinfoil condensers with thick paper dielectric compressed between metal plates, and placed in a solid air-tight iron box filled with special insulating material of an oily nature to maintain the insulation. We cannot enter into the consideration

of the circumstances under which condensers have been or are being applied, as they are used only in isolated cases at present.

At all events, the results depicted in Figs. 36 to 38

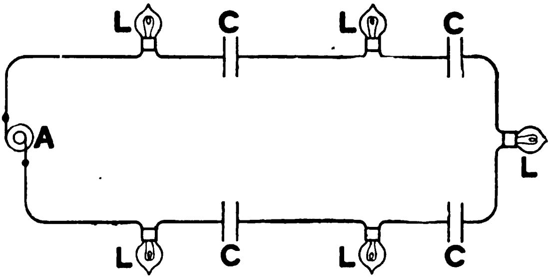

FIG. 38.—Condensers in Circuit.

are closely related to many beautiful experiments with alternating currents of extra high pressure and frequency, which certainly seem to foreshadow great advances on the

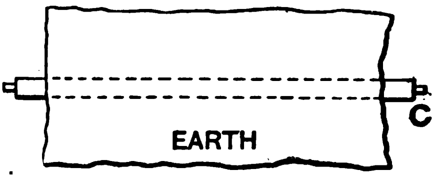

FIG. 39.—Electric Cable as a Condenser.

methods of electrical distribution and lighting as at present carried out.

34. CAPACITY IN ALTERNATING-CURRENT CIRCUITS (*cont.*).—The reader will probably have been puzzled by the statement made at the end of the preceding para-

graph, to the effect that every ordinary electric circuit possesses more or less capacity. Such is the case, but the capacity is *in parallel with the circuit*, not in series with it as in Figs. 35 to 38.

In Fig. 39, *C* is an electric cable laid direct in the ground, or in a conduit. The conductor forms one coating of the condenser, the insulation of the cable the dielectric, and the outer metal sheathing (if any), material of the conduit (if metal), or the Earth, the other coating. This state of things may be diagrammatically represented as in Fig. 40, where we may imagine the conductor of the

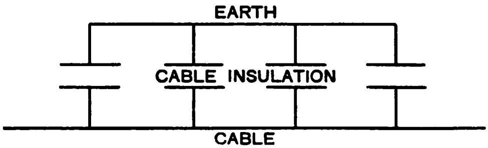

FIG. 40.—Capacity of Cable.

cable as joined at intervals to the coatings of condensers, the other coatings being connected with Earth. From this it is clear that the capacity is in parallel with the cable.

If the cable have no metal sheathing, and be placed in a roomy conduit, the air surrounding it and also the conduit (if non-metallic) form part of the dielectric of our imaginary condenser system; and the capacity is then much less, as the "coatings" of the condenser are farther apart.

Suppose there are two cables running side by side in a pipe or conduit, or in the ground, as represented in Fig. 41, which cables may or may not form part of the same circuit: we may then look upon the two cable

conductors as the respective coatings of the condenser, and the two insulating coverings, etc., in between, as the dielectric. The conception of this state of things as a condenser is not so easy as in the case of a single cable laid in the ground; but it is made clearer in Fig. 42, which represents a section of what lies between one

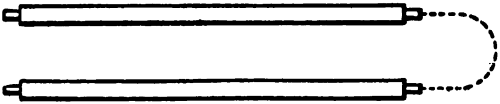

FIG. 41.—Capacity of Cables.

conductor and the other. The break in the condenser dielectric (cable insulation) caused by the presence of the cable sheathing or containing pipe, the earth, or air, practically makes little difference in the "condenser

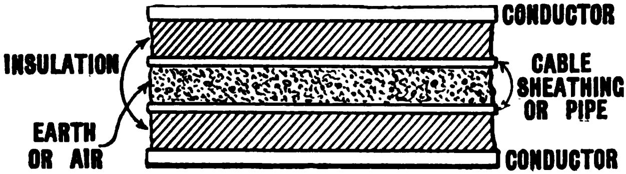

FIG. 42.—Capacity of Cable.

action" between the two cable conductors, as the cables usually lie close together.

The greater the length of the cables, and the closer together or to Earth they are, the greater their capacity. As a rule, armoured cables have greater capacity than unarmoured ones; and the capacity of unarmoured cables is increased when they are placed in iron conduits. The

capacity of underground armoured mains varies from about ·3 to ·6 microfarads per mile. It depends somewhat upon their size and construction, and is reduced by employing paper instead of india-rubber as dielectric.

35. Effect of Capacity in the Circuit.—The effect of capacity upon the current in an alternating-current circuit is exactly opposite to that of inductance, for it assists or tends to assist the current to rise to its maximum value sooner than it would otherwise do, whereas inductance retards or tends to retard the current (Chap.

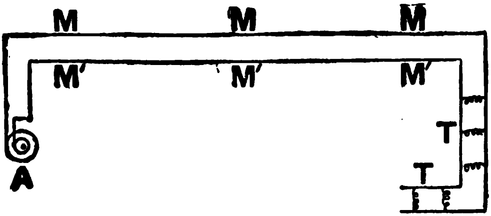

Fig. 43.—Capacity in an Alternating-Current Circuit.

IV.). This effect is the same whether the capacity is in series or in parallel with the circuit.

In Fig. 43, *A* is an alternator, the mains from which run for a long distance side by side, and feed a number of transformers, etc. For convenience we place the transformers, *T T*, at the far end of the circuit, and think of the condenser effect of the first portion. The alternator is constantly pumping electricity backwards and forwards between the mains *M M M* and *M′ M′ M′*, and these may be looked upon as the opposite coatings of a condenser. Let us suppose the alternator first pumps from *M* to *M′*; electricity will be heaped up, so to speak,

on M', and a deficit left on M, M' being + and M −. Now, neglecting for the moment the latter end of the circuit, suppose the alternator were suddenly stopped: there would then be a momentary return flow of electricity from M' to M through the alternator; in other words, the condenser would discharge itself. If the alternator go on working, however, it is obvious that the electricity heaped up on M' helps or increases the flow when the alternator begins to pump from M' to M. M then becomes + and M' −, and when the alternator again reverses its E.M.F., the + charge on M flows round to M', and helps

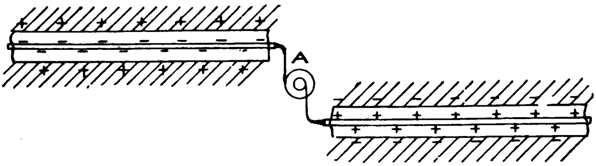

FIG. 44.—Capacity of Cables.

the ordinary current. This auxiliary current, if we may so call it, is generally termed the *condenser current*, and is clearly greater the greater the capacity of the mains. In the above explanation we have to suppose that the alternator is pumping to and fro very slowly, whereas the reversals of E.M.F. really take place several times a second (§ 43).

When the "go" and "return" mains do not run side by side, the condenser action may be pictured as follows:— Suppose the alternator to pump from left to right (Fig. 44), a surplus is heaped up on the right-hand cable, and a deficit created in the left-hand one; influence takes

place, and − and + charges respectively are influenced (or induced) on the outsides of the cables, as shown by the signs. If the alternator E.M.F. suddenly stopped, there would be a momentary current from right to left through the alternator. It is clear, therefore, that when the alternator reverses its E.M.F., there will be a greater transference of electricity (from right to left) than there was when the alternator first started and pumped from left to right. The left-hand cable will then become + ly. charged, and the right-hand one − ly. charged, and the discharge will help the alternator when it again reverses its E.M.F.

There is one difficulty which will probably have occurred to the reader, and that is, that the two cables in Fig. 43 being connected across at various points by transformers, etc., are not, consequently, strictly analogous to the insulated plates of a condenser. In Fig. 45, for instance, *C*, *C*, *C*, etc., are condensers representing the capacity of the two cables, *T*, *T*, *T*, etc., the primary coils of transformers connected between them, and *A* the alternator. Now of course, any metallic cross-connection would prevent the charging of the condensers with a steady direct pressure; but it is conceivable—and, indeed, is proved by practice—that with a rapidly alternating pressure, the condenser action is not perceptibly affected if the cables be connected across by some *non-inductive resistance*—glow-lamps for example. When *inductive resistances*, such as transformers, are joined to the cables (Fig. 45), the capacity effect will be reduced in consequence of the inductance thus put in circuit, though when a transformer is fully loaded with glow-lamps or other non-inductive work, its inductance becomes

negligible. Capacity and inductance tend to neutralize each other only when both are distributed along the whole length of the circuit, as in Fig. 45. In Fig. 43, the capacity of the first part of the circuit would be little affected by, or have little effect on, the inductance at the far end (§§ 37, 47).

A circuit is *inductive* or *non-inductive* according as it has appreciable or negligible inductance. Similarly, as regards capacity, it is here suggested that we might speak of circuits as being *capacious* or *non-capacious.*

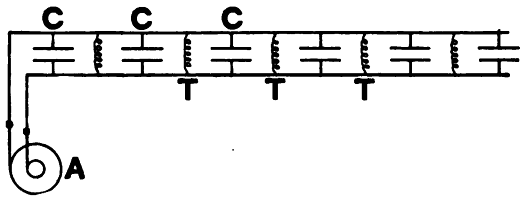

FIG. 45.—Capacity and Inductance on Cables.

36. INDUCTANCE, CAPACITY, ETC., IN A DIRECT-CURRENT CIRCUIT.—In direct-current work it is generally sufficient to liken a current to a steady flow of water through a metal pipe, the rate of flow representing current, the pressure on the water—E.M.F., and the resistance of the pipe—resistance in the electrical circuit. But here there is no good analogy for inductance, or for capacity; which two quantities are nearly always present in an alternating-current circuit. Consequently, some other help is necessary to enable us to picture in our minds the phenomena of an alternating current, and to compare them with those of a direct current.

In a course of lectures delivered at the Royal Institution, in 1895, Professor Forbes employed various mechanical analogies to illustrate electrical phenomena, and these we shall here make use of, with certain extensions and modifications.[1]

In Fig. 46 (*a*), *T W* is a short length of thick wire, which is supposed to be held vertically by its upper end, *T*, between the fingers and thumb of the left hand. Twist the top of the wire with the fingers and thumb of the right hand continuously round in the direction indicated by the curved arrow, and assume the twisting force applied to correspond with the E.M.F. in the electric circuit, and the rotation of *T W* to represent the current. Then, assuming that the wire is merely steadied by the left hand while it is being twisted by the right, *T W* corresponds with an electric circuit in which there is practically no resistance, inductance, or capacity; for it may be set rotating, kept rotating, and stopped, without appreciable effort—*i. e.* the current may be started or stopped at once, or kept up with a very small expenditure of energy.

In Fig. 46 (*b*), a large paper vane, *V*, is fastened to the wire. The effect of this is to oppose continuous air resistance to the rotation of *T W*, although it does not appreciably retard the setting up or stopping of that rotation. This air resistance must be compared with electrical resistance, and the arrangement then corre-

[1] The teacher or student should not be content with merely explaining or reading through the account of the following experiments, but should himself experiment with the simple contrivances depicted in Figs. 46 and 47.

sponds with a circuit in which there is appreciable resistance, but practically no inductance or capacity. If the same twisting force be applied as in case (*a*), the rotation of the wire will not be so rapid; in other words, with a given E.M.F., the presence of resistance diminishes the current.

In Fig. 46 (*c*), a disk of lead, *L*, or other heavy body,

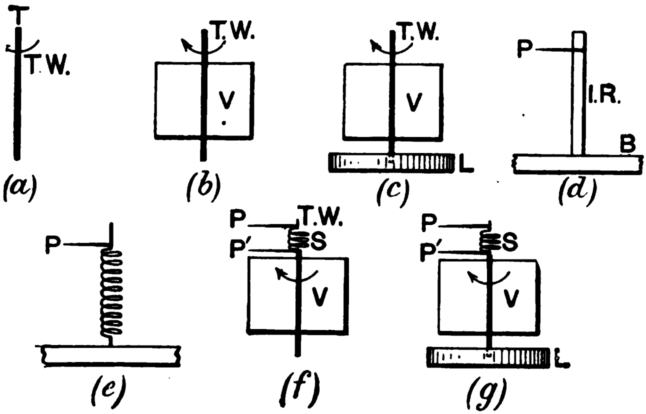

FIG. 46.—Mechanical Devices illustrating the Phenomena of a Direct-Current Circuit.

is tightly fixed to the end of *T W*. Now, while the air offers little or no resistance to the turning of *L*, on account of its shape; the latter, because of its inertia,[1]

[1] *Inertia* is that property of a body in virtue of which it resists being set in motion, having its motion changed, or being stopped when in motion. The inertia of a body depends upon its weight (or, more strictly, its mass), and also, to some extent, upon its shape. Force is necessary to overcome inertia, for it requires considerable force to set a heavy body (a flywheel, for instance) in motion, and

opposes considerable momentary resistance to the setting up of motion in *T W*, and it also tends to prevent the sudden stopping of *T W*. The addition of *L* therefore has the effect of adding inertia to the contrivance as a whole, and it will be found to require appreciable effort to set *T W* rotating; and when in motion it will resist any sudden stoppage. This mechanical inertia is comparable with the inductance (sometimes called *electric* or *electro-magnetic inertia*) in the electric circuit, the effect of which is to oppose momentarily the starting, changing, or stopping of a current (Chap. *IV.*). Fig. 46 (*c*) thus presents the mechanical analogy of a circuit with resistance and inductance, but without capacity.

In the above examples E.M.F. has been likened to a twisting or rotating force, current to rotation, electrical resistance to air friction or resistance, and inductance to inertia. We must now get something to represent capacity. In Fig. 46 (*d*), *I R* is an india-rubber or other flexible rod or tube rigidly fixed at the bottom, say, to a block of wood, *B*, which cannot move; and *P* is a pointer (such as a pin) stuck into the upper end of *I R*, to indicate its movement. It will now be shown that this arrangement is typical of a condenser. If E.M.F. be applied to a condenser, there will be a momentary current due to the rush of electricity into one of its coatings (or set of coatings) and out of the other, which, in amount, will depend upon its capacity; and the displaced electricity will represent the charge in the condenser. If the E.M.F.

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also considerable force to stop it. When a body is in motion, it is said to have *momentum*.

be removed, and the condenser left insulated, it will retain its charge: but when the condenser terminals are connected by a conductor, it will discharge itself, there being a sudden rush of electricity (momentary current) in the opposite direction.[1] Turning now to our mechanical analogue, Fig. 46 (*d*); on applying a twisting force (E.M.F.) to the top of *I R*, there will be a certain rotation of *P* (current) until the force with which *I R* tends to untwist equals the twisting force. The amount of twist (charge) that can be put upon *I R* depends on its flexibility (capacity), and on the twisting force (charging E.M.F.) applied. When *I R* has been twisted as much as possible, let its top be fixed (insulated) by means of a clamp; it will then represent an insulated charged condenser. Now release the clamp, and *I R* will fly round, as indicated by *P*, this being equivalent to discharging the condenser, the momentary movement of *P* representing the momentary current of discharge. It is evident that *I R* might be replaced by a coiled spring, as shown in Fig. 46 (*e*). These experiments (*d* and *e*) only serve to show the effect of capacity in a condenser circuit, as distinguished from one which is completely closed to allow of the continuous passage of electricity.

Fig. 46 (*f*) illustrates a circuit with capacity (due to the light coiled spring *S*), and resistance (due to *V*), but practically no inductance. *S* has two pointers, *P* and *P'*,

[1] The discharge of a condenser charged by a steady pressure, is really oscillatory in nature; and the analogy fits the actual conditions if we suppose that, on release, *I R* flies round a little too far, then returns, then goes back, thus making a certain number of diminishing oscillations before it comes to rest.

fixed one at each end, and when S is untwisted, P and P' should be exactly in line as viewed from the top. Now begin to twist the top of the wire, $T\ W$, keeping the eyes fixed on the pointers. It will be found that P moves round a little in advance of P' (if the spring is not too thick) before V begins to rotate, this representing the preliminary charging of the conductor; P keeping in advance of P' all the time the rotation is continued (the permanent charge in the conductor). If, now, the twisting force (E.M.F.) is suddenly stopped at $T\ W$, V will continue its motion through a short distance, until P' catches up with P, this being representative of the discharge from the conductor, which tends to prolong the current.

In Fig. 46 (g), the disk of lead, L, is added to represent inductance in the circuit. On applying a twisting force (E.M.F.) to the top of the wire, P first moves round slightly in advance of P', then the inertia (inductance) of L has to be overcome, and at last V gets up full speed (current). On trying to stop the rotation (current), the momentum of L (E.M.F. due to inductance) and untwisting of S (discharge due to capacity), but principally the former, tend to prolong the rotation (extra current); this, be it remembered, being the case of a direct-current circuit.

37. INDUCTANCE, CAPACITY, ETC., IN AN ALTERNATING-CURRENT CIRCUIT.—In the preceding paragraph, mechanical illustrations of the phenomena of the direct-current circuit were given. In his lectures (p. 89), Professor Forbes followed up these analogies still further; but, like most others, they must not be carried too far. The last portion of the preceding paragraph paves the way for their application to the alternating-current circuit.

In Fig. 47 (*a*) *T W* is a piece of thick wire. Hold it vertically at the top in the right hand, and steady it lightly with the left. Twist it rapidly to and fro, giving a turn first in one direction and then in the other, as indicated by the double-headed arrow. This represents the application or "impression" of an alternating E.M.F. to or on the circuit. If we suppose that *T W* has no inertia or flexibility, and that no resistance is opposed to its rotation, it may be taken to represent a circuit with no inductance, capacity, or resistance. The direction of twist (E.M.F.) and rotation

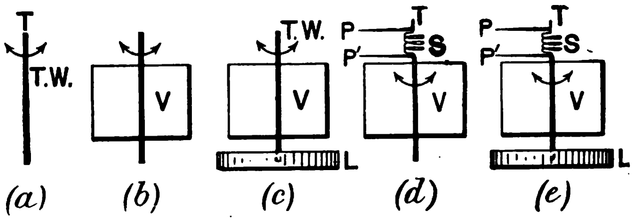


FIG. 47.—Mechanical Devices illustrating the Phenomena of an Alternating-Current Circuit.

(current) may be changed immediately, and one might almost say that the rate of rotation (strength of current) was uniform, though rapidly alternating in direction. This case may, therefore, be taken as an analogy for the imaginary alternating current represented by the "curve" in Fig. 31.

In case (*b*) (Fig. 47), a paper vane *V* is put on to represent resistance in the electrical circuit; but it must be supposed that it does not materially add to the inertia of the arrangement. Then, if the same alternating twisting force (E.M.F.) be applied to the wire as before (case *a*), the rate

of rotation (strength of current) will be less than in the first instance in consequence of V; but there being no inertia, as we suppose, the rotation (current) will change directly the twisting force changes, and will be always at the same rate. Here we have the representation of an alternating-current circuit in which there is practically only resistance, and no appreciable inductance or capacity. In Fig. 47 (*c*) is shown the mechanical analogue of a circuit with resistance (due to V), and inductance (due to L). Apply an alternating twisting force (E.M.F.) to the top of $T\ W$. The result will be that the rotation (current) will be far from uniform, it taking appreciable time to set up, stop, or reverse. Furthermore, the rotation (current) will "lag behind" the twisting force (E.M.F.); that is to say, the rotation (current) will start, stop, or reverse, after the twisting force (E.M.F.) has been started, stopped, or reversed.

In Fig. 47 (*d*), the spring S is introduced to represent capacity in the circuit. On applying an alternating twisting force to the top T, the effect of this flexibility (capacity) in the wire (circuit) will be opposite to that of inertia (inductance): for it will be found to assist the setting up and stopping of the rotation (current),[1] the movement of the pin-head P' being in advance of the twisting force (E.M.F.). Thus, if inductance and capacity be both present, and in their right amounts, no evidence of either will be found: in other words, capacity and inductance may neutralize each other's effects (§§ 35, 47).

[1] This seems to contradict what was said at the end of the preceding paragraph; but it should be remembered that here we are dealing with an alternating-current circuit, whereas § 36 refers to the direct-current circuit.

In Fig. 47 (*e*) is shown the mechanical analogy for a circuit with both inductance and capacity, as well as resistance. Here it should be noticed that the flexibility (capacity) increases the amount of turning of *L* (or rather of the supporting wire just above it) that can be done by a given force acting through a fixed distance; that is to say, it points to the fact that the addition of capacity to a circuit will decrease the effective inductance. Anyhow, it will be clearly seen that on applying an alternating twisting force to *T*, the effect of both flexibility (capacity) and inertia (inductance), provided they do not neutralize each other, will be to alter the rotation of *L* (current) with a given twisting force (E.M.F.) from what it would be were these properties absent.

In the mechanical analogies given above, the effect of inductance, as represented by inertia, is considerably greater than the effect of flexibility or capacity: but, of course, in some circuits there may be greater capacity than inductance, as might be represented by using a stronger spring, *S*, and a lesser weight, *L*, Fig. 47 (*e*). As a general rule, however, the effects of inductance preponderate.

With a given wire (circuit), in which there is principally inertia (inductance), the average rate of rotation (current) will be much greater in the case of a unidirectional twisting force (E.M.F.) than in the case of an alternating twisting force. In other words, a direct constant E.M.F. will set up a greater current in a given circuit than will an alternating E.M.F. of the same maximum value. For in the first case inductance will exert its effect only on making and breaking circuit, or when the current strength

is suddenly changed: whereas in the latter case, its effects will be in evidence the whole time.

With a steady direct E.M.F. the current is uniform, but with an alternating E.M.F. it is wavy or undulatory, *i. e.* constantly varying in strength. Even if the impressed alternating E.M.F. were constant in value, as in the experiment described in § 30, this would be the case, because of inductance, etc.: but as the E.M.F. of an alternator continually varies in strength as well as in direction (§ 42), the waves of current are much more accentuated.

Perhaps it is hardly necessary to point out that one

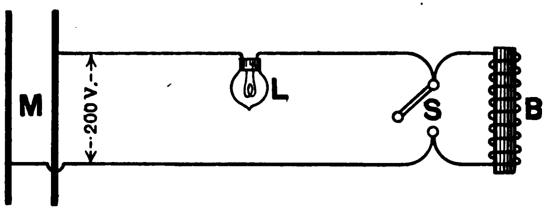


FIG. 48.—Effect of Inductance.

particular in which the above mechanical analogies do not exactly fit the true condition of things, is that the resistance (air friction), inductance (inertia), and capacity (flexibility), are contained in separate parts of the circuit (wire); whereas in the real electric circuit these properties are, as a rule, more or less intermingled along the whole of its length. This fact, however, does not materially affect the application of the analogies.

*38. INDUCTANCE IN A CIRCUIT.—It has been stated several times that the effect of inductance in an alternating-current circuit is to cut down the current. The following

experiment conclusively proves this. The circuit *L S B* (Fig. 48) is fed at a virtual[1] alternating pressure of, say, 200 volts, from the mains *M*. *B* is a laminated iron bar, built up of thin wires, on which are coiled several turns of thick wire of negligible resistance, which may be short-circuited by the switch *S*. *B* obviously possesses considerable inductance, whereas the rest of the circuit has very little. The light given by *L* depends upon the strength of the current passing through it, and is a convenient indicator of it. Suppose that when *S* is closed so as to cut out *B*,

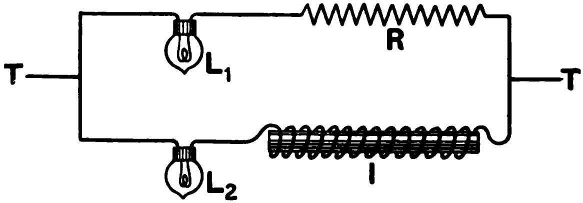


FIG. 48A.—Effect of Inductance.

the lamp is fully lighted; then when *B* is put in circuit by opening the switch *S*, the lamp will burn dimly, or perhaps show no light at all, proving that the effect of inductance is to reduce the current permanently. This effect is the same as if a back E.M.F. had been introduced into the circuit, which, in fact, is the case, the back or counteracting E.M.F. being that due to the inductance of *B*.

If a direct current is used, the insertion or cutting out of *B* will make no appreciable difference, as its resistance is small; except, perhaps, a faint flicker of the lamp at the

[1] See § 45.

moment of closing or opening S; but this would be hardly noticeable.

The same phenomena may also be illustrated as in Fig. 48A. Here are two circuits joined up in parallel between T, T. One circuit consists of a lamp, L_1, and a non-inductive resistance R; and the other of a similar lamp, L_2, and an inductive coil and core, I. The resistances R and I being the same, when a sufficient direct pressure is applied at T, T, both lamps will light up equally. If, however, an alternating pressure be applied, though L_1 may light up well, L_2 will give very little or no light, because of the inductance of I.

In alternating-current work care must be taken not to run single conductors (or conductors connected with one pole of the system only) through a metal pipe or tube for any distance. The effect of so doing, if the pipe were of iron or steel, would be to increase the inductance of the circuit and set up eddy currents in the pipe, and this inductance would naturally result in a considerable drop of pressure. In other words, the conductor (or conductors) and the pipe would act like a sort of elongated choking coil (§ 50). If the tube were of non-magnetic metal, there would be little or no inductance, but eddy currents would still be induced in the conduit, tending to heat it and waste energy. With concentric conductors, in which one conductor is of tubular form and surrounds the other, in the same cable, there is no chance of such a thing occurring.

39. Effects of an Alternating Current and of Inductance and Capacity on the Insulation of a Circuit.—In a conductor carrying a given virtual alternating current, it would seem that there is a greater tendency

for the electricity to leak through or break down the insulation than in the case of a direct current of the same value; for the reasons that in the first case it is moving rapidly backwards and forwards, and that the maximum value of the impressed E.M.F. is 1·41 times its virtual value (§ 45); while in the latter case it is flowing steadily in one direction, and the E.M.F. is also steady.

Let us illustrate this by an analogy. Consider a pipe, *P* (Fig. 49), with water flowing into it, as resembling a conductor carrying current; and suppose the material of the pipe to represent the insulation round the conductor. Then, if the pressure of water causes a fracture of the pipe,

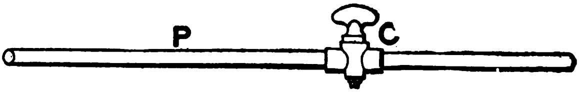


FIG. 49.—Effect of an Alternating Current on the Insulation of a Circuit.

it is clearly analogous to the breaking down of the insulation of the conductor. Now it must be evident that there is a greater strain on the sides of the pipe when the water is rapidly moving to and fro (alternating current), than when it is flowing steadily in one direction (direct current).

The effects of inductance and capacity in a direct-current circuit are observable only on making or breaking the circuit, or on suddenly changing the strength of current therein; but in an alternating-current circuit they exert a continual influence on the current, and also, indirectly, on the insulation of the circuit.

Fig. 50 presents an analogue. Here *S* is a stand carrying two bearings *B B′*, in which is mounted an upright glass tube *G*, which may be rotated by the handle *H*. A portion

of the glass is cut away, and a short length of rubber tubing, *R*, inserted, to represent capacity in the circuit. Down the centre of both glass and rubber tubes passes a metal wire which stands for the conductor, the glass tubing being looked upon as the insulating covering. The friction of the bearings and of the vane *V* corresponds with electrical resistance, and the inertia of the lead disk *L* represents inductance. The strain on the glass tubing, to the

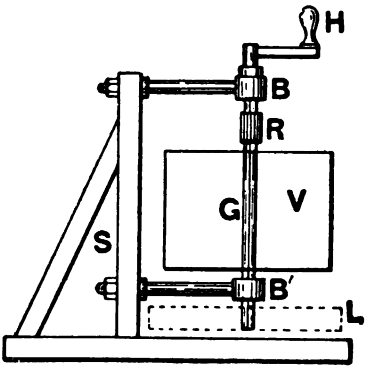


FIG. 50.—Strain on the Insulation of a Circuit.

outside of which *V* and *L* are fixed, may be taken as analogous to the strain on the insulation in an electrical circuit. We will first take a case in which *L* is removed —*i. e.* where there is no inductance in the circuit. Now, if *H* be rotated steadily in one direction (steady direct current), the strain on the glass tubing (insulation of the circuit) will be comparatively small: but if *H* is sharply and continuously turned, first in one direction and then in the other, clearly a good deal of strain is thrown on *G*, but

this is lessened in proportion to the flexibility of *R* (capacity of the circuit). This seems to point out that if a circuit has capacity but no inductance, the presence of the former will not increase the strain on the insulation, but rather the reverse. If *L* be now put on (inductance put in circuit), with continuous rotation (direct current), an extra strain will be thrown on *G* at the moment of starting, stopping, or altering the speed of rotation (current); and it will be the greater the more suddenly the starting, stopping, or alteration of the speed is brought about. The reason of this is that the flexibility (capacity) exists at the near end of the circuit, while the inertia (inductance) is all at the far end; a condition of things which obtains in electricity distribution work when the "feeders" supplying the distribution network have great length (§ 218). If the inductance, as represented by the inertia of *L*, were more distributed along the circuit, the extra strain on the insulation would be correspondingly lessened: while if it were all at the near end—*i. e.* if *L* were placed in the position of *R*, there would be practically no strain on the insulation directly due to inductance or capacity, except when the current (rotation) was suddenly stopped.

In the case of alternating rotation (alternating current) the strain on *G* will be continuous and very considerable if the condition of things be as represented in the figure; so much so, in fact, that if *G* is not thick enough or has any flaws in it, it will be fractured (insulation broken down). But if the inductance and capacity be more intermingled, the strain will be lessened: and if the inductance be all brought to the near end of the circuit, it will be still further reduced. This mechanical analogy affords a capital

illustration of the opposite effects of capacity and inductance in the circuit, and the fact that one may neutralize the other.

The presence of dynamos and other electro-magnetic apparatus, such as motors and arc lamps, is the main cause of inductance in direct-current circuits. Alternating-current circuits generally have much more inductance than direct-current ones, because of the numerous transformers therein; though, by the way, the inductance of these decreases as their load increases, when the load is non-inductive, as in the case of glow-lamp lighting. Now, thinking of the mechanical analogy (Fig. 50), it would appear that the more suddenly the full E.M.F. (whether direct or alternating) is thrust upon a circuit, with capacity at the near end and inductance at the far end, the greater will be the extra strain on the insulation. In most circuits, whether direct or alternating, but particularly in those with inductance—however distributed—considerable strain is thrown on the insulation if the circuit be broken rapidly. As an analogy of this latter effect in direct-current circuits, if, while the water is flowing (Fig. 49) the cock, *C*, is suddenly turned off, a great strain will be thrown on the pipe. An illustration of this may be found in some houses, where water is supplied direct from the main, and therefore at considerable pressure, and old-fashioned taps are used. On suddenly turning the tap off, the momentum of the water expends its energy on the pipe. Screw taps are designed to prevent this sudden strain being thrown on the pipes.

The strain due to inductance is not very noticeable on "making" the circuit, though its analogue is observable in

the mechanical illustrations. On breaking the circuit, inductance is very manifest, as it shows itself in the form of an "extra-current" arc or spark. Now it is a common but very erroneous idea that the more suddenly any circuit is broken the better, as the extra-current spark tends to destroy the ordinary switch contacts. This spark, or arc, represents energy, and if this energy is prevented from expending itself in the form of a spark or otherwise, it will wreak its force somewhere else—viz. on the insulation

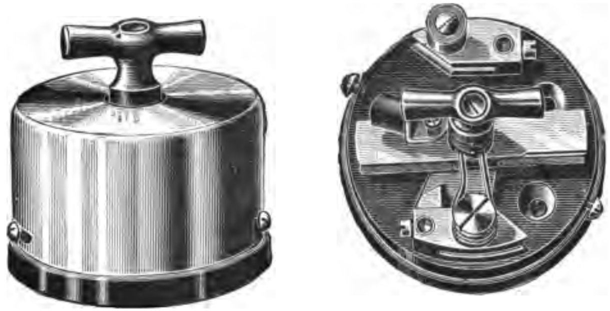


FIG. 51.—Switch with Carbon 'Make' and 'Break' Contacts (Siemens Bros.).

of the circuit. Main switches for circuits having large inductance, should therefore be so designed that the circuit is both made and broken gradually. A small switch fulfilling the above conditions is depicted in Fig. 51. On one of the fixed contact pieces, and on one end of the movable contact arm, there is a short cylinder of carbon. When putting the switch on, the carbons come into contact first of all, then the one on the movable arm, being mounted on a spring-hinged pivot, gives way to allow the arm to go into place. When the switch is put off, the carbon

contacts, and the slight arc formed between them, momentarily prolong the connection of the circuit. Other patterns of such switches are illustrated and described in Chap. II.

Though these switches were probably designed for the primary purpose of preventing or minimizing the "spark-wear" at the contacts, it will be evident that they also ease the strain on the insulation of the circuit.

Messrs. Cowans (Ltd.) have designed a switch which, on opening, first throws a non-inductive resistance in circuit and then short-circuits the coil or coils, the inductance of which it is desired to minimize. These may be the exciting coils of a dynamo or alternator, or any other inductive circuit. The switch is shown in Fig. 52, the construction and connections being given diagrammatically in Fig. 52A. Corresponding parts in these two figures are similarly lettered. The positive and negative supply leads are connected with the fixed contacts marked + and −, and the ends of the inductive circuit, *I C*, with the lower fixed contacts *C*, *C*. *C′*, *C′* are two other contacts permanently connected with + and − through non-inductive resistances, *R*, *R*, fixed at the back of the switch. Except when the switch is "off," and *I C* is short-circuited through the fuse *F*, by reason of the movable contacts *M C* engaging with the fixed contacts *F C*; the two sides of the switch, which are pivoted at *P*, *P*, are entirely separate, electrically speaking; but they are operated simultaneously by means of the ebonite handle *H*. The laminated contacts *L C*, *L C*, as well as *M C*, are fixed to the switch-bars *S B*, which carry *H*. The upper pair of contact tongues, *C T*, are hinged to the underside of *S B* at the points *X*. The pecu-

liar shape of C', C' in Fig. 52 is for the purpose of enabling

FIG. 52.—Switch for Inductive Circuits (Cowan's).

them to engage with cross-pins on the contact tongues C T,

and so cause contact to be prolonged at these points. Bearing in mind that the switch-bars are pivoted at *P*, *P*, it will be evident that the lower ends of *L C*, *L C* never leave the fixed contacts *C*, *C*. Supposing the switch to be

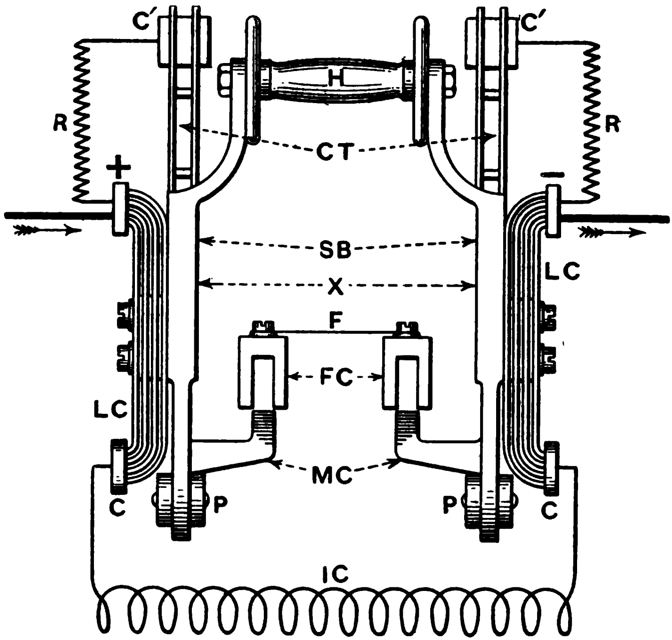


Fig. 52a.—Diagram of Switch for Inductive Circuits (Cowan's).

on, as in Figs. 52 and 52a, its connections are as shown at Fig. 52b (I.); and the current flows straight through *I C*, *R* and *R* being short-circuited. When the switch is pulled "off," its action is as follows. First of all *L C*, *L C* leave + and −, thus throwing *R*, *R* in series with *I C*,

Fig. 52B (II.). As the switch-bars move further over, *M C*, *M C* engage with *F C*, thus short-circuiting *I C*, Fig. 52B. (III.); and the moment after this occurs, the current is cut off by *C T*, which are pulled off sharply by means of the springs seen in Fig. 52. The final condition of the circuit is shown in Fig. 52B (IV.). The current having an alternative path through *R*, *R*, there is little or no sparking when the main circuit is

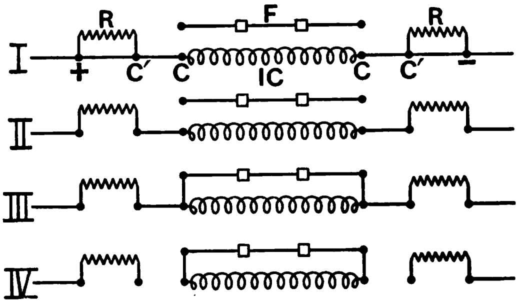


FIG. 52B.—Diagram of Circuit Changes.

broken at *L C*, *L C*; and because by that time the inductive coil or coils have been short-circuited through *F*, there is very little sparking when the circuit is finally broken at *C T*, the break here being a very sharp one. Sometimes only one resistance, *R*, is necessary, the other resistance being replaced by a short-circuiting strip.

These resistances are made up in a very compact form, and are mounted at the back of the switch base. The resistance wire is covered with a carbonized material which will stand a very high temperature without injury. The wire

is wound between mica disks clamped together between iron cheeks, the edges being finally coated with a fireproof insulating cement.

Some electricians will probably disagree with the statement that it is necessary in practice to "make" as well as "break" alternating-current circuits gradually, and will maintain that there is really no excessive stress on the insulation of a circuit when the full pressure is suddenly thrust upon it. Theoretical considerations, however, seem to indicate otherwise; the amount of extra strain (if any) thrown on the circuit, at the moment of making it, appearing to depend upon the relative distribution of the inductance and capacity, as already pointed out.

The matter of slow "making" probably only becomes of really practical importance when pressures above, say, 2000 volts are used; or when the circuits consist of a number of miles of cables of large capacity. Professor Forbes has arranged for slow "making" and "breaking" on the Niagara power circuits, and it is now being done at Deptford, and elsewhere.

So far, we have assumed that the presence of a capacity in a circuit lessened the inductance, and therefore, also, the strain on the insulation when the current was started in it. If, however, the capacity is just sufficient to neutralize the inductance, so that there is no reactance (§ 48), we get a new effect termed *electrical resonance*, which itself strains the insulation. This effect is dealt with in § 55.

It is interesting to note that on breaking a high-pressure alternating-current circuit, the switch may show a large, small, or no spark at all, according to the point in the

current wave where separation occurs. Thus if the circuit happens to be broken at the moment the wave is at its peak or maximum (Fig. 59), the largest spark will be obtained, while if the current is just reversing, there will be no appreciable spark.

40. ELECTRIFICATION OF CONDUCTOR DIELECTRIC.—There is one particular point in which the mechanical analogies fail, and that is, they furnish no good example for the action taking place across the dielectric or insulation—viz. the *electrification* due to condenser action. In Fig. 53 is given a section of a cable conductor, its insula-

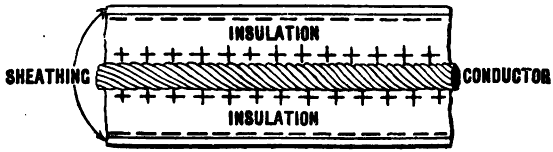


FIG. 53.—Electrification of Conductor Dielectric.

tion, and the surrounding sheathing, pipe, or Earth. Let the conductor be carrying a steady direct current, and suppose that particular portion of it under consideration to be at a higher potential than the Earth [1]; it will then have a steady + charge. Influence will take place, and a − charge will be induced on the inner surface of the metallic sheathing of the cable, or other surroundings, the system acting like a condenser (§ 34). Now these charges will mutually attract each other, and will soak into the dielec-

[1] There is a gradual fall of pressure or potential along a conductor carrying a direct current; but there is almost always bound to be a P.D. between the conductor and the Earth, and the conductor will be either + ly. or − ly. charged with respect to the Earth.

tric and tend to approach nearer to each other, and so, in a sense, lessen the thickness of the insulation surrounding the conductor. With alternating current, on the other hand, although the electrification of the dielectric ("soaking-in" action) is not nearly so great, as the charge of the cable is constantly and rapidly alternating in sign, there is a small loss of power due to this cause. The dielectric in fact offers a certain opposition to the setting-up of alternating charges, which is known as *dielectric hysteresis,* and which is further explained in § 60.

*41. EXPERIMENT ON INDUCTANCE.—The effects of inductance have been described in the immediately preceding paragraphs, principally by means of mechanical analogies. The following experiment further shows its effects, and should be considered in conjunction with those depicted in Figs. 48 and 48A.

In Fig. 54, *L* is a glow-lamp, connected through the switch *S,* and wires, + and −, with a source of direct E.M.F. *C* is a coil of fairly fine wire, with a removable iron core, and is connected as a shunt to the lamp. The resistance of *C* should be of such a value that when a steady current is flowing, the lamp filament is just perceptibly red. At the instant of making the circuit, the lamp will momentarily glow more brightly than when the current is steady; on breaking the circuit, the lamp will momentarily flash with great brightness. In the first case the counter E.M.F. due to inductance, as indicated by the small dotted arrow, will momentarily oppose the normal pressure in the shunt circuit, *C,* so that the P.D. at the lamp terminals *T T* will be momentarily increased, and will consequently send a momentarily stronger current

through the lamp. On breaking the main circuit at *S*, the field of *C* will collapse, generating a momentary and much greater E.M.F. than in the first instance, in the direction shown by the larger dotted arrow. A momentary current will then flow through *C* and *L* in a counter-clockwise direction, and the lamp will flash up brightly in consequence.

Remove *C*, with its iron core, and insert instead a coreless coil having the same resistance as *C*, but wound as in Fig. 34, so that it shall have no inductance. Pass

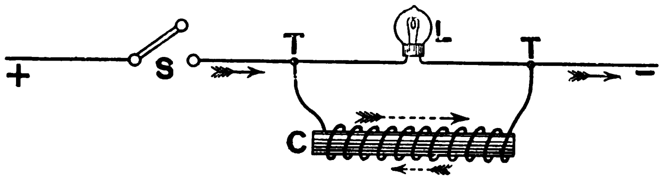


FIG. 54.—Experiment on Inductance.

an alternating current through the lamp and coil, of such a strength that the filament of *L* is perceptibly, but dimly, heated. Now substitute the former coil, *C*, with its core, and it will be found, in consequence of the inductance of *C*, that *L* is increased in brilliancy. The explanation of these different effects on the lamp is as follows. In the first case, the non-inductive coil shunts a certain amount of current from the lamp circuit, thus lowering the P.D. between *T*, *T*, but otherwise exerts no effect. In the second, where the coil has the same resistance, and also considerable inductance, the back E.M.F. due to the latter, constantly opposes the normal pressure, offering a

kind of extra resistance in addition to the ordinary resistance of the coil (§§ 48, 49, 50). Thus the total apparent resistance of the coil is increased, and less current is shunted away from the lamp, which consequently glows more brightly.

The difference in the result of this experiment, as compared with that illustrated in Fig. 48, is accounted for by

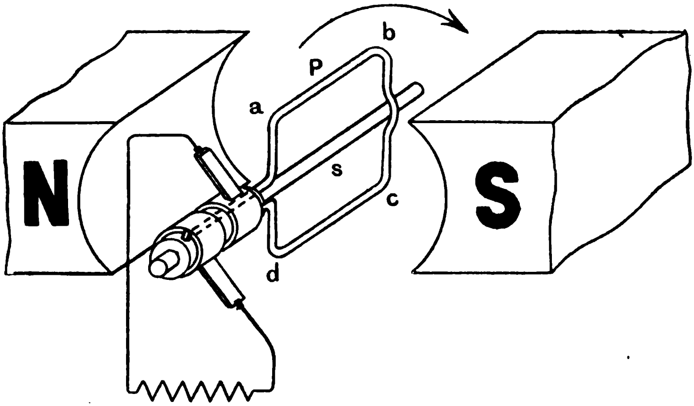


FIG. 55.—Simple Alternator.

the fact that in one case the inductive coil is *in series* with the lamp, while in the other it forms a *shunt* thereto.

42. GRAPHICAL REPRESENTATION OF AN ALTERNATING CURRENT.—The E.M.F. of an alternator is continually altering in value, as well as in direction, *i. e.* it is in the form of waves, and the waves of current thereby set up are further accentuated by the inductance and capacity in the circuit.

To show approximately what an alternating current is

like, one may draw a picture, in the form of a curve, of the changes which take place in the strength and direction of the impressed E.M.F. which sets up the current; and this will enable us to explain what is meant by the *sine curve* or *sine wave*, terms frequently used in speaking of alternating currents.

When a simple coil of wire is rotated in a magnetic field, it has an alternating E.M.F. induced in it. A simple 2-pole field and coil are shown in Fig. 55, and we will consider what happens to the top half, p, of the coil, $a\ b\ c\ d$, when the latter is evenly rotated on its shaft s, in the direction shown by the curved arrow.

Now p will, if viewed sideways from one of the pole faces, N or S, have an up-and-down motion; and its apparent velocity will be variable during any one complete revolution of the coil; but the changes that take place will be repeated over and over again at regular intervals. This will be more clearly understood from Figs. 56 and 57. Fig. 56 represents the circular path traversed by p when the coil is looked at from the front end, only one pole, N, being shown for simplicity's sake; and as we suppose that the coil is being turned with uniform velocity, the actual rate of progress of p round its circular path will also be uniform. But if we look at p from one of the sides of the coil, it will appear to travel up and down in a straight line, $a\ b$ (Fig. 57), and its rate of motion in an actual up-and-down direction will not be uniform. When p has travelled round $10°$ from its topmost position, *i. e.* from p to p_1 (Fig. 56), its actual progress in a downward direction will be represented by the distance $p\ p_1$ in Fig. 57, which is relatively much less

than the circumferential distance $p\ p_1$ in the first figure. Another 10° travel is from p_1 to p_2 (Fig. 56), from p_2 to p_3, from p_3 to p_4, and so on; and as these distances are traversed in equal times, the apparent velocity of p, as viewed in Fig. 57, will at first be very slow, but will gradually increase until it reaches the 90° position, p_5. From p_5 to p_6 its apparent velocity will gradually decrease.

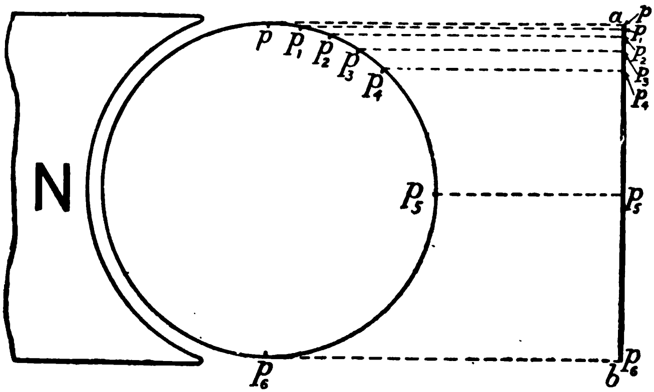


FIG. 56. (View from end of coil.) FIG. 57. (View from side of coil.)

The same thing will be observed when the coil is making its second half-turn, *i. e.* when p is travelling from p_6 back again to its topmost position.

Now, the E.M.F. induced at p, or rather in the side $a\,b$ of the coil, depends upon the rate at which it cuts the lines of the field, and supposing the field to be uniform, this depends upon its rate of motion in an actual up or down direction, as viewed in Fig. 57. It therefore follows that the E.M.F. in p will vary just as the rate of

its travel along the assumed path *a b* (Fig. 57) varies: and it will change from zero to a maximum during the first quarter-turn of the coil, from maximum to zero during the second quarter-turn, from zero to maximum, in the reverse direction, during the third quarter-turn, and from maximum to zero during the last quarter-turn: by which time it will have made one complete revolution. The other half, *c d*, of the coil (Fig. 55) will be acted upon in a precisely similar manner.

Motion of the kind described in connection with Fig. 57 is called *harmonic*, and obeys a simple law called the *sine law*. This can be explained by the aid of Figs. 58 and 59, which are closely related to the two preceding figures.

Looking at the coil from the collector or front end (Fig. 55), the path described by the point *p* (Fig. 58) will be a circle, having its centre at *O*; *p o* being its zero or starting position, and 1, 2, 3, 4, 5, etc., successive points on its journey during one revolution of the coil.

The sine curve, or curve of E.M.F., is plotted as follows. Draw a horizontal line, in the same straight line as the horizontal diameter of the circle in Fig. 58, and call it the TIME BASE (Fig. 59). Since the point *p* moves with uniform velocity round its circular path, distances measured along the time base may be taken to represent either "time from the beginning of measurement," or "distance moved by *p* round its circular path." *p* is connected to its "centre of travel" or axis, *O*, by the radius *R* of the circle in which it moves, and this is clearly the greatest height to which it can rise, as in position *O* 4 (Fig. 58). We therefore take this height as the maximum height for our sine curve (Fig. 59),

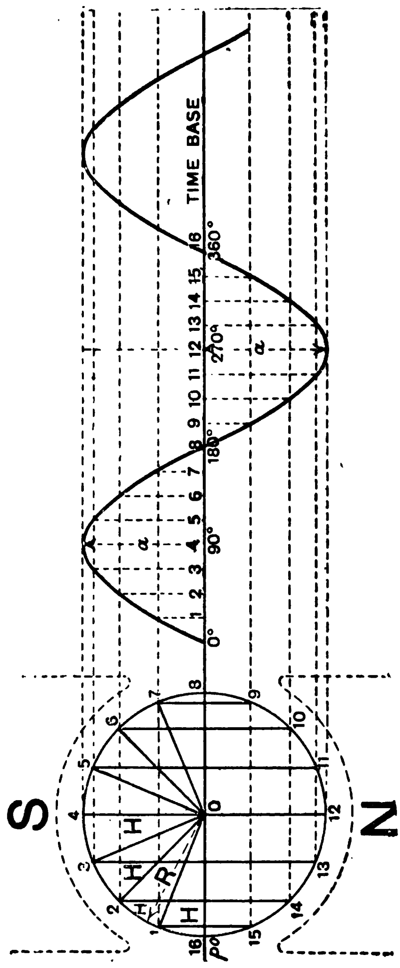


Fig. 58.

Fig. 59.

Plotting of the Sine Curve.

which represents the rise, fall, and reversal of E.M.F. The radius R will make an angle with the horizontal diameter of the circle, which will have zero value when p is in the position $p\ o$, and will increase as p travels round the circle, until, at position 4, the radius is 90° from its original position. To draw the E.M.F. curve, we must first take a length along the time base, and call it 360°; this being conveniently made equal to half the length of the circumference of the circle in which p moves.[1] This length is then equally divided up, and we get a straight line with subdivisions representing the distances moved by p along its circular path, or, what is the same thing, the angles made by the radius with its first position in its revolution round the centre O; and these divisions, as before pointed out, may also be taken to represent time.[2]

Suppose p has reached the point 1, we take a distance along the time base equal to half the circumferential distance, 0 1, and at that point erect a perpendicular: where this cuts a horizontal line drawn through point 1 on the circle, we get one point on the curve. In the same way for position 2, we take half the distance along the

[1] Distances along the time base are proportional to circumferential distances, and may be drawn to any scale. In the present case they are equal to *half* the circumferential distances which they represent, this being the usual scale adopted.

[2] If p has moved from its zero position to position 2 (Fig. 58), the radius will have travelled round 45°. When p reaches the position 4 the radius will have travelled or have described an angle of 90°. When p has made one half-turn, *i. e.* when it has reached the position 8, the radius may be said to have travelled 180° from its zero position. When p has made one complete revolution, we say that its radius has travelled round or described an angle of 360°.

circumference 0 2, and mark this off on the time base, then erect a perpendicular, and where the latter cuts a horizontal line drawn through 2 on the circle, we get the second point on our curve. This operation being repeated for different positions of p round its circular path (3, 4, 5, 6, etc.), a series of points is obtained, which, when connected, are found to lie on a wavy line called the sine curve (Fig 59).

This curve depends upon the relationship that the distance, H, of each position of p (above or below the horizontal line) bears to the radius, R. For the greater H is, that is, the greater the distance p is above or below the base line; the more effectively is it cutting the magnetic lines of the field, and the greater is the E.M.F. H is a maximum at the positions 4 and 12, and these are consequently the maximum points on the curve. The connection between H and R is as follows:—

$$H = R \sin A,$$

where A is the angle which the radius, R, makes with the horizontal line, in the particular position taken.

The sine of the angle A (Fig. 60) (written *sin A* or *sine A*) is the number obtained by dividing the length of the perpendicular or height H by the length of the hypotenuse (side opposite the right angle) or third side R, in this case the radius of the circle, —*i. e.*

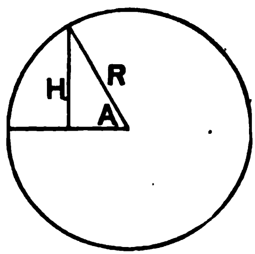


Fig. 60.—Sine of an Angle.

$$\sin A = \frac{H}{R},$$

this ratio being dependent on the angle itself, not on the individual length of either of its sides.[1]

The curve obtained shows the variation in the E.M.F. of a simple alternator, such as that illustrated in Fig. 55, during one revolution of its coil or armature. The E.M.F. is at zero when the plane of the coil or armature is at right angles with the lines of force of the field, and gradually rises, reaching a maximum when the plane of the coil is parallel with the direction of the field. The field in this case is assumed to be uniform; if it is not so, the simple sine law no longer holds good, and the E.M.F. curve will be more or less altered in form. In practical alternators, owing to the non-uniformity of the fields, and the various shapes of coils used, the form of the E.M.F. curve may vary considerably from that of the true sine curve. The design of alternators, however, has been brought to such a

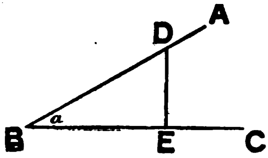


FIG. 61.—Sine of an Angle.

[1] Let *A B C* (Fig. 61) be any angle, *a*, of which the sine value is required. Take any point, *D*, in either side, say in *A B*, and drop therefrom a perpendicular, *D E*, to the other side, *B C*, cutting it at *E*. Then *B D E* will be a right-angled triangle, of which *B D* is the hypotenuse, and *D E* the perpendicular. Now, in such, the ratio $\frac{perpendicular}{hypotenuse}$, i.e. $\frac{DE}{DB}$, represents the sine value of the angle *a*. If the angle remain the same (in the present case it is 30°), no matter how long the sides *B D* or *B E* may be, or from which point or side the perpendicular is dropped, the ratio $\frac{perpendicular}{hypotenuse}$ will always be the same. In the present case, for instance, it is ½, *i.e.* sin 30° = ·5. A table of sine values is given in Chap. *VI.*

pitch of perfection that they may be made to give a true sine wave of E.M.F., or one which differs in shape therefrom, according to the ideas of the designer. The fact of thus being able to obtain variously shaped waves of E.M.F. within certain limits, is of importance; and one question which naturally arises is:—what is the most efficient form of wave for a given circuit? This is a matter, however, beyond the scope of this book.

43. FREQUENCY.—The E.M.F. in the coil shown in Fig. 55 is at zero in the upright position there depicted, but gradually increases until the plane of the coil lies horizontal—*i. e.* until the coil has moved through 90° and has no lines through it: it then gradually decreases, reaching zero when the coil has made one half-turn. In the second half-turn the E.M.F. will again gradually rise and fall, but this time in the reverse direction. This rise, fall, and reversal, and the corresponding distance travelled by the coil, are shown in Figs. 58 and 59.

If the coil is connected up with an outer circuit, in one revolution the induced E.M.F. and resulting current will make two *alternations,* or one complete *period* or *cycle:* and the *rate of double alternations per second,* or *number of complete periods* or *cycles per second,* which is termed the *frequency* or *periodicity,* will depend upon the number of revolutions which the coil makes in that time. Thus, supposing it revolves 600 times in one minute, the frequency of the E.M.F. and of the current set up will be 10.

Frequency is denoted by the symbol ~, thus 70 ~ signifies a pressure or current making 70 complete periods per second—*i. e.* having a frequency of 70.

The frequency of alternating currents, as used for ordinary work in this country, varies from 25 ~ to about 100 ~, the tendency in central station work being to adopt low values, especially for power-transmission work. For special purposes E.M.Fs. of very much higher frequency are sometimes employed.

The rise and fall of the current in *one* direction should be called an *alternation;* but this term is sometimes employed to indicate a complete reversal, *i. e.* a *period* or *cycle,* a misuse of the term which is somewhat confusing. Referring to Fig. 59, the portion of the curve from 0 to 180 is really an alternation, and the portion from 0 to 360 a cycle or period, and the symbol for frequency (~) being derived from the shape of the curve, should assist the student in remembering this. An *alternation* is, as its name indicates, an alternative wave or alteration in direction. Thus a frequency of 80 ~ means 80 periods, or 160 alternations per second.

44. FREQUENCY OF ALTERNATORS.—In the case of a simple coil rotating in a 2-pole field, it has just been shown that the frequency is equal to the number of revolutions per second. Practical alternators are, with few exceptions, constructed with multipolar field-magnets, as well as a number of coils: but the frequency may be got by simply multiplying together the revolutions per second and the number of pairs of poles, a consequent pole or two facing poles counting as a single one.

Example.—An alternator has 12 pairs of poles (N and S), and runs at 300 revolutions per minute. Each coil will pass through 12 fields in one revolution—*i. e.* there will be 12 complete reversals or waves of E.M.F. (~) in

each revolution. Consequently, the resulting frequency will be :—

$$\frac{300}{60} \times 12 = 5 \times 12 = 60 \sim.$$

45. Virtual Volts and Amperes.—The E.M.F. of a practical alternator is continually rising, falling, and reversing, in much the same manner as described in § 42; and the current in the circuit must rise, fall, and reverse *in sympathy though not necessarily in step* with the E.M.F. (§ 47).

It is clear that we cannot take the maximum points of the pressure or current wave as the nominal value, for the pressure or current are only at these maxima for comparatively short periods. What is rightly called an alternating E.M.F. of, say, 100 volts, must at some times be considerably above 100 volts, and at other times at zero. Similarly, an alternating current of, say, 10 amperes, is at times greater than 10 amperes, and at others less. We must take a value, called the *virtual value,* which is equivalent to that of a direct E.M.F. or current which would produce the same effect. And those effects of the E.M.F. and current are taken which are not affected by rapid changes in direction and strength; in the case of E.M.F. or pressure—the reading on an electrostatic voltmeter; and in the case of current—the heating effect.

Thus, a *virtual E.M.F.* of 100 volts is one that would produce the same deflection on an electrostatic voltmeter as a direct E.M.F. of 100 volts: and a *virtual current* of 5 amperes is that current which would produce the same heating effect as a direct current of 5 amperes—say, on a

"bank" or group of incandescent lamps. But both pressure and current will be continually varying above and below these values.

The virtual value of an alternating E.M.F. or current having a sine curve form (Fig. 59) is about ·707, or rather less than three-fourths of its maximum value. For example, an E.M.F. which alternates between maximum values of 100 volts in one direction, and 100 volts in the other, will have a virtual value of about 70·7 volts. Similarly, a current which alternates between maxima of 10 amperes in one direction, and 10 amperes in the other, will have a virtual value of about 7·07 amperes. The reciprocal[1] of ·707 is 1·41, so that if any virtual value of pressure or current be multiplied by this number, the product will give the approximate maximum value. Thus, a virtual alternating pressure of 220 volts alternates between maxima of ($220 \times 1{\cdot}41 =$) 310 volts in either direction; and a virtual current of 50 amperes between ($50 \times 1{\cdot}41 =$), say, 70 amperes in one direction, and 70 amperes in the other.

A given virtual alternating pressure throws more strain on the insulation of a circuit than a direct pressure of the same value (§ 39): and in this connection it should be remembered that, as we have just pointed out, any given virtual pressure fluctuates between maximum values nearly half as high again as its virtual value. If the wave of

[1] The reciprocal of any number, n, is obtained by dividing it into unity—*i.e.* reciprocal of $n = \frac{1}{n}$. Thus reciprocal of $\cdot707 = \frac{1}{\cdot707}$ $= 1{\cdot}41442 \ldots$ or say, 1·41. The product of any number multiplied by its reciprocal is unity: thus $\cdot707 \times 1{\cdot}41442 \ldots = 1$.

pressure differ from the sine curve form, a matter which depends on the design of the alternator, as mentioned at the end of § 42, the maxima may be as much as twice the virtual value.

The difference between *virtual* and *effective* values of pressure and current is explained in § 56.

46. AMPLITUDE AND PHASE.—The *amplitude* of an impressed (virtual) alternating E.M.F. or current is the maximum value or height of each wave. Thus, in Fig. 59, the distances *a a* represent the amplitude of the waves of E.M.F.

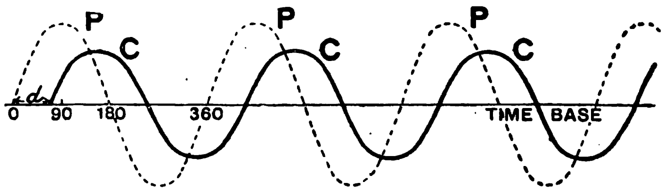


FIG. 62.—Lagging Current.

Both E.M.F. and current undergo periodic changes of strength, or, in other words, they pass through different *phases* or states. If we take a case where the current rises, falls, and reverses exactly at the same time as the E.M.F., the current would then be said to be *in phase* or *in step* with the E.M.F.: but, as already explained, this is not always so, the current wave being more often *out of phase* with the E.M.F. wave, owing to the effects of inductance and capacity. The frequency of the current is, however, always the same as that of the impressed E.M.F.

47. LAG AND LEAD.—It was explained in § 32 that the

effect of inductance in a circuit is to cause the current to take time to "grow," and time to die away. In fact, the current does not generally start till after the E.M.F. has been impressed on the circuit, and does not stop until after the E.M.F. has been stopped or reversed. Inductance in an alternating-current circuit consequently causes the wave of current to *lag* behind the wave of E.M.F. This is depicted in Fig. 62, where the dotted curve, *P*, represents the E.M.F. or pressure wave; and the other curve, *C*, the current wave. Starting from the left-hand end of the horizontal line or time base, it will be seen that the current starts after the E.M.F. starts, and reverses after the E.M.F. reverses, and so on. In other words, the current *lags in phase* behind the E.M.F., although its frequency is exactly the same.

The amount of the *lag* is measured in degrees as set out along the time base. Thus the lag is indicated by the distance, *d*, between the beginning of the pressure curve and the beginning of the current curve, and is in this case about 70°. The lag due to inductance may be anything up to 90° (a quarter period), but cannot exceed this.

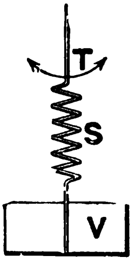


FIG. 63.

The effect of capacity in a circuit is generally said to cause the current to *lead* in phase, but this effect is rather difficult to conceive, though we will endeavour to explain it by means of a mechanical analogy, such as has already been employed. Apply an alternating twisting force to the top of the wire, *T* (Fig. 63); the action of the spring, *S*, being taken to represent the effect of capacity, and the

rotation of the vane, *V*, movement of electricity or current. On commencing the experiment the twisting force (E.M.F.) must first be applied *before* the rotation (current) will commence; but after a time, though it will be difficult to discern, the resilieney or rebounding effect of the spring will act so as to cause the vane, *V*, to move in *advance* of the twisting force (E.M.F.), thus representing the current *leading in phase.* The explanation of the effect of capacity, as given in §§ 35 and 37, will also assist the reader to understand what is meant by the term. As a general rule, alternating currents lag more or less in phase, as the inductance usually greatly preponderates over the capacity: but, on very long lines, or by purposely introducing capacity into a circuit, the lag may be neutralized or even exceeded by the lead, and the current will then be either in phase with the pressure, or it may lead in phase.

There has been some objection to the terms "lead of current" or "lead in phase," principally on the ground that they tend to convey the idea that the effect precedes the cause—*i. e.* that the current is in advance of the E.M.F. causing it. The latter is true in one sense, but untrue in another. Of course, there can be no flow of electricity in a circuit until E.M.F. has been applied: but if the circuit has capacity, and supposing firstly that a direct E.M.F. is applied, the current will on starting be momentarily greater than the ultimate steady current; and it will again be momentarily greater on stopping the E.M.F.

In § 31 we likened an electrical circuit to a pipe filled with water. This analogy may be extended by supposing

that an electrical circuit with capacity is like a pipe circuit only partially filled with water. Then when water-motive force is applied—for instance, when the connection of the circuit with a cistern or reservoir is established by opening a tap—there will be a momentary rush of water (till the pipe is filled up) that will be greater than the ultimate steady flow. The hydraulic circuit, however, does not offer a good analogy for the electric circuit when capacity is taken into account. The capacity of a rigid pipe for water is fixed, whereas the capacity of a conductor for electricity depends upon its surroundings, and on the

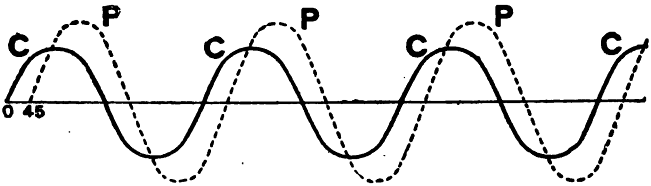


FIG. 64.—Leading Current.

E.M.F. or P.D. applied.[1] The illustration just put forward will serve to give the reader an idea as to how capacity may be said to "suck" the current out in advance of a direct E.M.F., but does not afford a parallel for the discharge flow, or for the action with an alternating E.M.F.

The lead of current due to capacity in an alternating current circuit is best illustrated by the mechanical analogies given at the beginning of this paragraph and in § 37, while a partial explanation is given in §§ 33, 35, and

[1] See the Author's *First Book of Electricity and Magnetism*, Second Edition, § 159.

55. Fig. 64 represents the current curve, *C C C*, leading in advance of the pressure curve, *P P P*.

Lag and lead are further dealt with in §§ 56, 57, and 59.

48. Reactance.—The resistance offered by a conductor to a steady flow of electricity is expressed in ohms; and this value is the same whether the conductor is coiled up or stretched out, and is unaffected by the presence of neighbouring conductors. With a constantly changing current, such as an alternating one, the *apparent resistance* offered to its flow is greater if the circuit conductor be coiled up than if it be straight, is affected by the presence of neighbouring conductors, and also depends upon the frequency. In short, Ohm's simple law as enunciated in Chap. *II.* cannot be applied to alternating-current circuits.

This apparent additional resistance in the circuit is due to the combined effect of self and mutual induction, and is called reactance.[1] The inductance is increased by the presence of electro-magnets or coils of wire in the circuit, but is neutralized by capacity; while the mutual induction depends upon the presence of neighbouring conductors. Thus:—

$$\text{Reactance} \propto \frac{\text{inductance}}{\text{capacity}}$$

Reactance constitutes a kind of *spurious resistance*, over and above the ordinary or *ohmic resistance* (§ 57).

[1] The term *inductance* was originally introduced to take the place of *self-induction*, but it is now, as in this particular case, taken to include *mutual induction* also, as the two are in many cases inseparable, especially in alternating-current work. The distinction between self and mutual induction is given in Chap. *IV.*

49. REACTANCE AND IMPEDANCE.—*Impedance* is the "virtual" or total resistance offered to the flow of an alternating current; and from what was said in the preceding paragraph, is clearly the combined effect of the ohmic and spurious resistances in a circuit; or in other words:—

$$\text{Impedance} \propto \text{resistance} + \text{reactance}.$$

The two terms reactance and impedance must not be confused. It should be easy to remember that *reactance* refers only to the *reactive effects* in the circuit, or what is otherwise called the "spurious resistance"—*i. e.* an extra resistance brought about when the flow of electricity is not steady. *Impedance,* on the other hand, implies the virtual or total resistance which *impedes* the flow of an alternating current of electricity.

The connection between resistance, reactance, and impedance is further explained in § 57.

*50. DIFFERENT ACTION OF RESISTANCE AND REACTANCE ON CURRENT. CHOKING COILS.—There is a very important difference in the obstruction offered to an alternating current by ordinary resistance and by reactance, as the reader will have observed in performing the experiments mentioned in §§ 38 and 41. Resistance obstructs the current by dissipating its energy, which is converted into heat. Reactance, on the other hand, obstructs the current by setting up an alternating E.M.F. in opposition to the impressed E.M.F., and so reduces the current in the circuit *without wasting much energy*, except by hysteresis in any iron magnetized (Chap. *VI.*).

This may be regarded as one of the advantages of

alternating over direct currents, for, by introducing reactance into a circuit, we can cut the current down with comparatively little loss of energy. This is generally done by increasing the inductance in a circuit, and consequently also its reactance and impedance, by means of a device called variously a *reactance coil, impedance coil, choking coil,* or "*choker.*"

Figs. 65, 66, and 67 illustrate the principle of choking coils. In Fig. 65, C is a coil of thick wire provided with a laminated iron core, $I\,C$, which may be either fixed or movable. In the first case, the inductance, and therefore also the reactance of the coil, is invariable, with a given frequency. In the second case, the inductance and consequent reactance may be respectively increased or diminished by inserting the core farther within the coil or by withdrawing it.

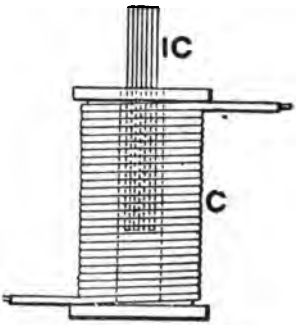


FIG. 65.—Simple Choking Coil.

In Fig. 66, C is a coil of thick wire with a fixed laminated iron core, $I\,C$, and a movable thick copper sheath or sleeve, $C\,S$. When $C\,S$ is apart from C, the latter will have its maximum inductance—*i. e.* its greatest choking effect: but this will decrease as $C\,S$ is slipped further and further on to C. When $C\,S$ is placed over C, mutual induction takes place between C and $C\,S$, the latter forming a closed secondary circuit. The E.M.F. due to the inductance of the coil C will then be more or less occupied in setting up currents in $C\,S$, instead

of opposing the pressure in and so weakening the current in the main circuit. The sheath, *C S*, however, also absorbs some of the energy of the current flowing through *C*; hence a choking coil on the first-described principle (Fig. 65) is more generally used.

The choking coil depicted in Fig. 66 is virtually a small transformer, of which *C* is the primary coil, and *C S* the secondary coil. Now the copper sheath, *C S*, has very little resistance, and the currents set circulating in it—which represent energy transferred from the primary

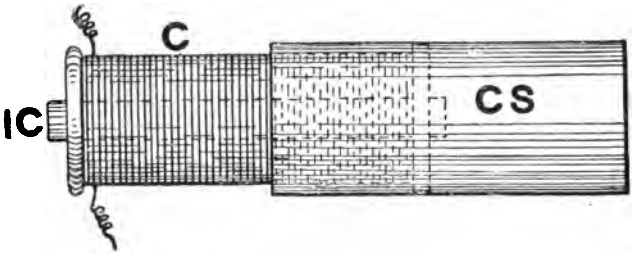


FIG. 66.—Sheathed Choking Coil.

circuit, *C*—are comparatively large. If we could increase or diminish the resistance of *C S* at will, instead of slipping it on or off *C*, we should be equally well able to regulate the choking effect of the apparatus as a whole. This is sometimes done in practice, as diagrammatically represented in Fig. 67, where *I C* is a laminated iron core, on which are wound the fixed primary and secondary coils *P* and *S*. *P* is in the main circuit, and joined up to *S* is an adjustable resistance, *R*, with some kind of sliding contact, *C*, by which the amount of *R* may be increased or diminished. The iron core, *I C*, may or may not

be movable. Supposing, firstly, that it is fixed. The greater the resistance of the secondary circuit, $S\ R\ C$, the smaller will be the currents induced therein, and the less the energy of inductance absorbed from the primary circuit, P: consequently, when R is small, the least choking effect will be exercised, but as R is increased, the choking effect will increase. If $I\ C$ is movable, the choking effect may be further diminished or increased by respectively withdrawing or inserting it.

*51. PRACTICAL FORMS OF CHOKING COIL.—All the

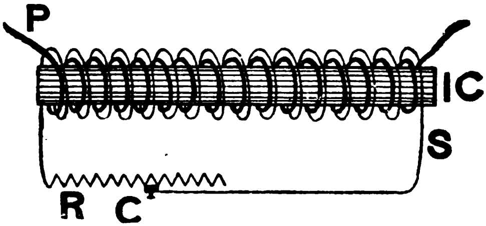


FIG. 67.—Choking Coil with Variable Closed Secondary Circuit.

"chokers" described here belong to the class depicted in Fig. 65—*i. e.* they consist of one winding with a movable or fixed core. Choking coils acting on the principle shown in Fig. 66 are used in America, but besides being less efficient, as already pointed out, they are also more expensive in construction. Owing to inefficiency, the principle shown in Fig. 67 is not altogether satisfactory when the choking coil is in circuit for hours at a time.

Fig. 68 shows a choking coil for heavy work, as made by Messrs. Johnson and Phillips. The coil consists of one winding in two sections, the bobbin being divided midway

FIG. 68.—Choking Coil (Johnson and Phillips).

by an insulating "cheek." A guide-tube of "pressspahn"[1] is fixed to the top of the bobbin, and in this slides the core. The latter is made of a bundle of fine iron wires securely bound together, and it is hung at one end of a steel cord, which makes a couple of turns round a pulley, and terminates in a counter-weight; the cord being fixed at one point to the pulley, so that it cannot slip thereon. A sensitive adjustment is secured, the hand-wheel operating a worm which gears into a spur wheel fixed alongside the pulley. The latter may be locked in any required position by means of the small bolt at the right-hand end of its spindle. The terminals of the coil are at the back of the wooden stand, the switch at the top being so connected as to short-circuit it if neces-

[1] *Pressspahn* is a material made of compressed wood fibre. It is cheaper than vulcanite, and more durable than pasteboard.

sary. The height of the stand is 4 ft. 10 in., the particular size shown carrying a maximum current of 15 amperes, and at a certain frequency, choking down the P.D. of the circuit in which it is fixed from 1400 to 200 volts.

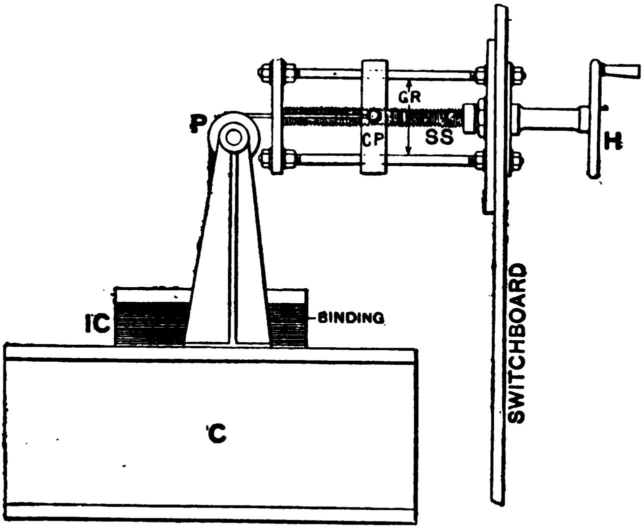


FIG. 69.—Choking Coil (Crompton & Co.).

Fig. 69 gives an outline of a choking coil made by Messrs. Crompton & Co., the main difference between this and the one just described being in the method of adjustment, and the absence of a counterweight. The coil *C*, and iron core *I C*, are both great in diameter, as compared with length; the core thus having to pass through only a relatively small distance to secure a large

difference in effect. The core, *I C*, is made up of fine soft iron wires bound together, and is fastened to one end of a steel band which passes over the pulley *P*. The other end of this steel band is secured to the cross-piece *C P*, which travels along the two guide rods, *G R*. The hori-

FIG. 70.—Choking Coil in Case.

zontal lines on *I C* represent the binding round the iron wires, the latter of course running in a perpendicular direction. The hand-wheel *H*, on the front of the switch-board, turns the screwed spindle *S S*, which is tapped into *C P*; and according to the direction in which *H* is turned, so *C P* moves either to the right or to the left, and *I C* is withdrawn from or dropped further into the coil. The design of the coil and the method of adjustment may be altered to suit different circumstances.

Fig. 70 shows a choking coil, or rather a collection of choking coils, fitted in a cast-iron case, from which the cover has been removed to show the interior. Each separate "choker" has two coils mounted on

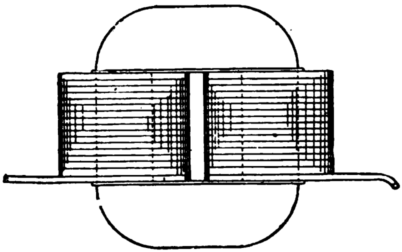


FIG. 71.—Choking Coil.

a laminated core, as illustrated in Fig. 71. These cores cannot be seen in Fig. 70, as strips of vulcanized fibre are placed horizontally between their ends and the holding-down bolts. The coils are relatively small, as the case which holds them is only 2 ft. long. This apparatus was made by the Electric Construction Company for the system of street lighting adopted at Lagos, W. Africa, where 50-c.p. incandescent lamps are run in series circuits off constant potential mains. A sketch of the connections is given in Fig. 72, where it will be seen that the choker (or

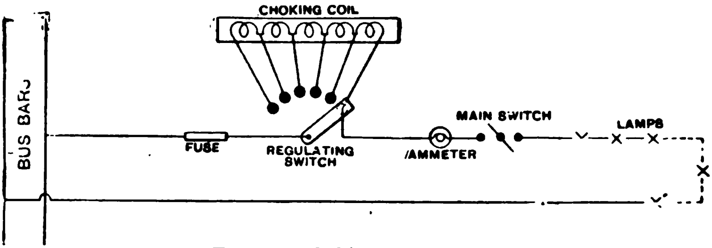


FIG. 72.—Choking Coil Circuit.

rather chokers) is joined up with a multiple-contact regulating switch. Each lamp is provided with an automatic short-circuiting cut-out, and should one, two, or more of them fail, a corresponding number of sections of the choking apparatus is put in circuit to take the place of the broken lamp or lamps, and thus keep the current constant. It must not be supposed that this arrangement of lamps, etc. is a general one; it being adopted to suit certain special conditions. The matter is cited as illustrating an application of choking coils.

Another type of choking coil, made by Mr. Leslie

Miller for very light work, consists of a fixed core and coil, the number of turns of the latter in circuit being varied by means of a sliding contact. A diagram of this arrangement is given in Fig. 73, and an exterior view in Fig. 74. *IR* is a laminated iron ring built up of soft iron ribbon. On this, but well insulated therefrom, is a coil of thickly-covered copper wire, one end of which, *E*, is free, *i.e.* unconnected with anything, while the other is joined to terminal *T*. *IR* is closely wound with the wire, *i.e.* the turns lie close side by side, not as shown in the figure. Pivoted in the centre of the ring and operated by a handle *H*, is a brass arm *A*, the end of which bends over and makes contact with the turns of wire on the outer edge of the ring, the insulating covering being scraped off for this

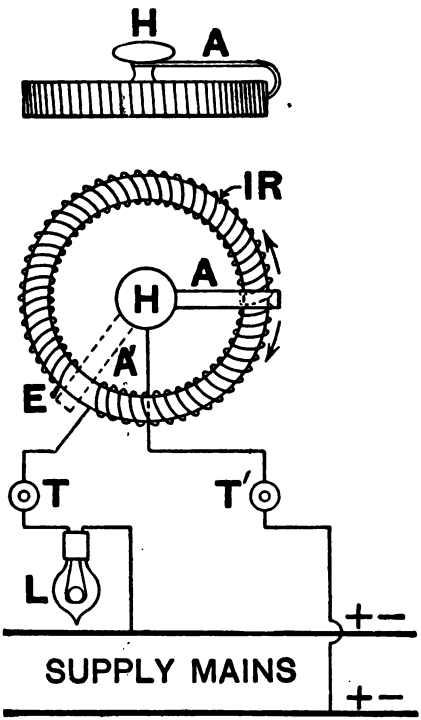


FIG. 73.—Small Choking Coil Circuit.

purpose, after the wire is wound on the ring, without however short-circuiting the neighbouring turns. *A* is connected with terminal *T′*, and the figure shows the connection of the choking coil to the mains, with one lamp *L* in circuit. If the arm *A* is in the dotted position *A′* no current will flow. By turning *H* one way or the other,

FIG. 74.—Combined Choking Coil and Switch.

more or less of the turns of wire will be put in circuit with the lamp, and the latter will give less or more light. It may appear that the actual resistance of the turns put in circuit has something to do with the cutting down of the current, but if the apparatus is well designed, the resistance of the whole of the coil should be such that if it were all put in circuit with the lamp without its iron core, *i.e.* without appreciable reactance, there would be

very little effect on the brightness of the lamp. For if the coil has much resistance as well as reactance, energy will be absorbed in heating the coil, and the current will not be cut down without material waste, the primary object of a choking coil. An exterior view (about half-size) is given in Fig. 74, where the handle and the terminals (*H* and *T T'* in Fig. 73) will be seen.

FIG. 75.—Combined Choking Coil and Switch fitted to Lamp.

These choking coils are suitable for regulating a single or even two or three lamps, but cannot be used for large currents. Fig. 75 shows this apparatus or *regulating switch*, as it is sometimes called (for it acts both as switch and regulator), fixed in conjunction with a glow-lamp.

*52. USE OF CHOKING COILS.—It has been shown that choking or reactance coils are made in many different forms; and that their use is to cut down, "choke," or "throttle" the pressure in a circuit or portion of a circuit; the principle of their action being illustrated by the experiments mentioned in § 38. In electric-light work for instance, a glow-lamp or group of lamps may be "turned down" or "dimmed" to any desired extent by operating a choking coil in its or their circuit. In theatres, music-halls, churches, etc., any number of lamps may be simul-

taneously raised or lowered in brilliancy by the use of choking coils. In ordinary house work, an alteration in the light is generally effected by simply turning lamps on or off, though a choking coil such as is shown in Fig. 74 is useful in some cases, *e. g.* in bedrooms, etc. Of course this turning down or lowering of the lights could be effected by inserting ordinary resistance in the circuit, but in this case, as previously explained, much of the energy taken from the lamps would be expended in heating the resistance, whereas by using reactance coils the current is cut down with very little waste.

The principal use of choking coils, however, is in connection with arc lighting, and for regulating purposes in central station work. One or two forms for arc lighting work are illustrated in Chap. I., where their use is fully dealt with. Something is said in § 58 as to the calculation of the inductance for a choking coil for a given circuit.

53. "Skin Resistance" or Conductor Impedance.—When a direct current begins to traverse a conductor, it commences to flow first at the surface, and then at last penetrates to the interior: when it stops, it leaves off first at the surface and lastly in the interior. This effect is due to the inductance of the conductor, and may be explained as follows. Imagine the conductor to consist of a number of separate small insulated wires packed closely together side by side (Fig. 76). Now when a current is started along these separate wires, mutual induction will take place between them, and momentary reverse E.M.Fs. will be set up therein. Clearly those wires which are nearer the centre and consequently completely surrounded by neighbouring wires will have stronger reverse E.M.Fs.

set up in them than those on or near the outer surface, so that a direct current will find less momentary opposition to it near the surface than in the interior of the conductor. Thus a direct current may be said to flow first at the surface and lastly evenly through the whole section of the conductor; the time occupied in settling down being only a fraction of a second, however. Again imagining our conductor as subdivided (Fig. 76), when the steadily flowing direct current is suddenly stopped, mutual induction will take place, and momentary "direct" E.M.Fs. (*i.e.* in the same direction as the current is flowing) will be set up in the separate wires, and will tend to

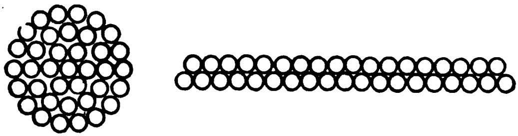


FIG. 76.

prolong the current. These induced E.M.Fs. will be greater in those wires in the centre than in those on the surface, hence the current will leave off first at the surface and lastly at the interior. If we suppose, for argument, that the conductor is subdivided into separately insulated conductors or wires, we may put down the effect to mutual induction: but if we think of the conductor as a whole, the effect may be attributed to self-induction (inductance), which is perhaps after all the real cause.

This phenomenon has been given the name of *skin resistance*, a bad and misleading term, as after all it is plainly an effect of induction and has nothing to do with

ohmic resistance: for if we take two conductors of equal length, resistance, and cross-section, one being of circular section and the other in the shape of a ribbon (Fig. 76), it will be found that the so-called "skin resistance" of the first is greater than that of the second, for the reason that the latter conductor is more spread out, *i. e.* the imaginary separate wires composing it are not so much under each other's inductive influence. The term "skin resistance" would lead one to think that with two or more conductors of equal cross-section, the phenomenon in question would be more marked in the one with the greater surface, whereas the reverse is the case. The Author has suggested that *conductor impedance* would be a better and more expressive name for this effect.

Although the effect of inductance is not very noticeable in straight conductors, there is no doubt that it exists therein, and is the greater the greater the mass and the more compact the shape of the conductor. With direct currents, however, its effects, in uncoiled conductors, may be disregarded, as such only occur at the moment of starting or stopping the current.

54. Conductors for Alternating Currents.—The inductance of a straight or thick conductor (*i. e.* its so-called "skin resistance") exercises a continual effect on the flow of an alternating current; which effect increases in proportion to the frequency of the current. When an alternating current commences to flow in a conductor, it starts first at the outer surface and then penetrates more or less to the interior; but, unless the frequency be very low, and the conductor small (presuming it to be of circular solid section), it may happen that very little or no

current flows through the centre. Let us try to picture the probable cause of this. When the current starts in one direction, the reverse E.M.F. due to inductance is, as was shown in the preceding paragraph, greatest at the centre; supposing the current to stop, the induced E.M.F. is again greatest at the centre, and is at the moment "direct," *i.e.* in the same direction as the current: but as the latter at this moment reverses, this direct E.M.F. acts in opposition to it. Thus the induced E.M.Fs., which exist principally in the centre, alternate as the current alternates, but are constantly opposite in direction. Though the effect of inductance in straight conductors is extremely small as compared with that in coiled ones (as in electro-magnetic apparatus), still it does exist, and Lord Kelvin has shown that in the case of a current at a frequency of 150 ~, the current penetrates the copper conductor to a depth of about three millimetres only, *i.e.* a little over one-tenth of an inch. At the ordinary frequency of 100 ~, it has been calculated that the current in a copper conductor at a depth of 12 millimetres (nearly ·5 in.) from the surface is only about one-seventh of its value at the surface. Thus the largest useful size of circular cable for alternating-current work at ordinary frequencies is about 19/14s, *i.e.* a strand made up of 19 wires, each of No. 14 size, the total diameter being about ·4 in. Larger sizes are less efficient than the cross-section of copper would seem to indicate.

Some writers aver that the effect just dealt with is due to capacity as well as inductance, and such is probably the case, though if capacity be taken into account the explanation becomes less simple. However the effect be

explained, it seems certain that the conducting power of a conductor for alternating currents depends not so much upon its mass as upon its surface, so that a hollow tube may conduct nearly as well as a solid rod of the same diameter: and with the same area of cross-section, a ribbon-shaped or tubular conductor is preferable to a circular stranded or solid one. As was mentioned at the beginning of this paragraph, the "skin resistance" or *conductor impedance* (§ 53) increases as the frequency increases; but unless either the frequency of the current or the thickness of the conductor be very great, it may be disregarded in practice for the sizes most commonly in use. Low-tension alternating cables for large currents have, however, to be designed with this point in view.

55. Electrical Resonance.—The mains of the London Electric Supply Corporation extend from their central station at Deptford to various distributing centres in the western and southern districts of London. Each "go" and "return" main up to about the year 1897 consisted of concentric copper tubes insulated from each other with tightly-compressed paper, and owing both to their shape and great length they possessed considerable capacity. Soon after the supply was started, the fall of pressure along the mains was found to be much less than anticipated, in other words, the pressure at the distributing ends was greater than could be then accounted for. After a time it was seen that this effect was due to the great length and consequent capacity of the mains, and the rise of pressure due to this cause has been given the name *electrical resonance*, though it is more popularly

known as "rise of pressure effect," "capacity effect," or "condenser effect."

In his Royal Institution Lectures (§ 36), Professor Forbes presented a mechanical analogy for this so-called "electrical resonance." A long spiral spring was suspended from the ceiling, the free end being held in the hand: and the end of the spring was pulled down and allowed to rise again at regular intervals and with small force. After a time, the spring accumulated energy by reason of its resilience, and its movements up and down showed greater amplitude than that which the operator gave it at each downward pull—that is to say, the spring "jumped" up and down of its own accord beyond the range of the hand at its lower end.

To construe this effect into electrical language, we must first of all assume that the direction of the axis passing down the centre of the spring is the direction of the circuit conductor (or rather part of it); that the elongation and shortening of the spring represent currents first in one direction and then in the other; and that the downward pulls stand for the impressed E.M.Fs. in one direction, there being no analogue for E.M.Fs. in the opposite direction, as the spring is not pushed up, but contracts of its own accord.

If both the E.M.F. and frequency be very low indeed, *i.e.* if the end of the spring be pulled down slowly and at long intervals, the "jumping effect" (capacity current) will be absent: but as the "frequency" of the downward pulls, or the E.M.F., as represented by the sharpness with which the spring is pulled, increases, so also will the jumping effect, until at last the movement of the spring

(current) will refuse to be governed by and will be out of step with the successive pulls (E.M.F. impulses) given by the observer. The above explanation is doubtless somewhat crude and weak, but it will serve to give the reader an inkling of the cause of electrical resonance, the effect being, as already stated, to lessen the fall of potential along the conductor or circuit in which it exists.

"Electrical resonance" is the effect of capacity on an alternating current in circuits (or portions thereof) in which the inductance is so counterbalanced by the capacity that the rèactance is nil. Then the current is exactly in phase with the impressed E.M.F. It is very seldom, however, that this exact balance occurs in practice, unless intentionally brought about; but when it does so happen, the effect is very marked, the pressure in the circuit rising enormously, and great strain being thrown upon the insulation of the circuit. In some cases the circuit pressure has been increased eightfold thereby!

56. Effective Volts and Amperes.—In § 45 an explanation was given of the meaning of the terms virtual pressure and virtual current. A virtual E.M.F. is about ·707 of the maximum values reached by the tops of the pressure curve if the latter is of the sine shape (Fig. 59), and varies slightly as the form of the curve varies. When we speak of the E.M.F. *impressed* on the circuit, we mean the virtual E.M.F. In nearly all circuits the impressed or virtual E.M.F. meets with an opposing E.M.F. of reactance, and the *effective E.M.F.* is something less than the virtual E.M.F., it being that pressure which is ultimately available for driving electricity round the circuit, or for doing work.

For illustration, let us imagine a given non-inductive

circuit, without appreciable capacity, containing a short-circuited choking coil; and suppose that a constant virtual or impressed E.M.F. is maintained at its ends, as in Fig. 48. While the choking coil is short-circuited, there being no opposing E.M.F. in the circuit, the whole of the impressed E.M.F. will be effective in driving electricity round—*i. e.* the virtual and effective E.M.Fs. will be equal. If the choking coil is thrown in circuit, the reactive E.M.F. due to its inductance will oppose the virtual E.M.F.; and the effective E.M.F. and consequent current will be proportionately reduced, and will be still further reduced if the reactance of the coil is increased, the virtual or impressed E.M.F. remaining constant the whole time.

Referring to what was said in § 45, if an electrostatic voltmeter be applied to the ends of a circuit, the reading will give the virtual volts under all circumstances, and if there be no reactance present, this reading will also represent the *effective volts.*

Current necessarily implies the flow of electricity, and a virtual current is that indicated when a reliable ammeter is put in circuit. If the current happens to be in phase with the pressure, this reading will also give what may be called the *effective current.* It has been shown, however (§§ 46 and 47), that the current is hardly ever in phase or step with the pressure; it usually lagging in phase, though it may sometimes lead in phase. The amount of this lag or lead is called the *phase difference* or *angle of lag or lead,* as the case may be, and the greater this is the less is the power of a given virtual current to do useful work. That proportion of the current which can do useful work may be called the *effective current.* When there is no

phase difference, the effective current is the same as the virtual current; but as the angle of lag or lead increases, so does the value of the effective as compared with the virtual current diminish.

The difference between virtual and effective current is further referred to in § 59.

57. CONNECTION BETWEEN INDUCTANCE, REACTANCE, IMPEDANCE, IMPRESSED VOLTS, AND VIRTUAL CURRENT. —We have seen (§ 48) that the reactance in an alternating-current circuit depends directly upon the inductance and inversely upon the capacity. In a circuit with negligible capacity, if L be the inductance, and n the frequency, the reactance will be $2\pi n L$.[1] The term L (inductance) is here understood to include both self and mutual induction. (*Vide* footnote, p. 129.)

Reactance or spurious resistance is, like ohmic resistance, independent of the current; but the current must be taken into account when we wish to find the volts necessary to overcome these resistances. Thus if C be any virtual current, $R\,C$ denotes the volts necessary to force it through an ohmic resistance R. Similarly $2\pi n L C$ will be the volts necessary to force the same current through an inductive or spurious resistance $2\pi n L$. This quantity $2\pi n L C$ represents, in fact, the counter E.M.F. of reactance, or the *reactive drop of volts;* just as $R\,C$ represents the *ohmic drop.*

[1] This formula requires an application of the differential calculus for its proof, so we will therefore take it for granted. π stands for the ratio of the circumference of any circle to its diameter, *i.e.* 3·1416 (approximately). L is usually termed the co-efficient of inductance.

Thus for example, if $C=60$ amperes, $n=80 \sim$ per sec., and $L=\cdot 005$ henry,[1] the E.M.F. of reactance will be $2 \times 3{\cdot}1416 \times 80 \times \cdot 005 \times 60 = 151$ volts.

If, as already stated, the reactive drop in an alternating-current circuit carrying a virtual current C be $2\,\pi\,n\,L\,C$ volts, it seems to follow that the total volts necessary to be impressed on the circuit will be equal to the sum of the volts required to send the given current through the ohmic resistance, and the volts equal to the opposed volts of reactance (*i. e.* $R\,C + 2\,\pi\,n\,L\,C$). This, however, is not the case, owing to the fact that the E.M.F. of reactance is not in phase (or cophasal) with the impressed E.M.F.; that is to say, the wave of alternating E.M.F. of reactance does not reach its maximum values at the same time as the wave of impressed E.M.F., but afterwards. In other words, the E.M.F. of reactance lags behind the impressed E.M.F.

The impressed or virtual volts necessary to set up a current of C virtual amperes in a circuit of known ohmic resistance R, and reactance $2\,\pi\,n\,L$, may be found as follows:—

Draw a horizontal line $A\,B$ (Fig. 77) proportional in length to the volts ($R\,C$) required to send the current through the ohmic resistance R of the circuit. From A draw $A\,C$ perpendicular to $A\,B$, and proportional in

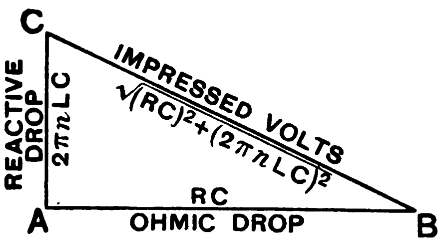


FIG. 77.—Impressed Volts and Drop.

[1] The *henry* is the unit of inductance (Chap. *IV.*).

length to the reactive drop, *i.e.* to $2\pi n L C$. Then join BC. The length of BC will represent the required value of impressed E.M.F.

Now CAB is a right-angled triangle, of which CB is the hypotenuse, *i.e.* the side opposite the right angle. In such, the square of the hypotenuse is equal to the sum of the squares of the other two sides (by *Euclid*, I. 47).

Thus:—

$$CB^2 = AC^2 + AB^2$$

and

$$CB = \sqrt{AC^2 + AB^2}$$

That is:—

$$\text{Impressed or virtual volts } (E) = \sqrt{(RC)^2 + (2\pi n L C)^2}$$
$$= \sqrt{C^2 \times \{R^2 + (2\pi n L)^2\}}$$
$$= C\sqrt{R^2 + (2\pi n L)^2} \qquad \text{(I.)}$$

Now as in Ohm's simple law:—

$$E = CR$$

and

$$C = \frac{E}{R}$$

we may write:—

$$\text{(Virtual) } C = \frac{\text{(Impressed or virtual) } E}{\sqrt{R^2 + (2\pi n L)^2}} \qquad \text{(II.)}$$

This may be termed the Ohm's law for alternating currents, $\sqrt{R^2 + (2\pi n L)^2}$ being, in fact, the impedance or "virtual resistance" in the circuit.

In words the above may be written thus:—

$$\text{Virtual current} = \frac{\text{Impressed E.M.F.}}{\text{Impedance.}}$$

If, in a steady-current circuit, we multiply together the current and the resistance, the product will give the E.M.F. in the circuit: or

$$C \times R = E$$

The same result follows in an alternating-current circuit, for multiplying the virtual current by the virtual resistance (impedance) will give us the impressed or virtual E.M.F., *i. e.*:—

$$\text{(Virtual) } C \times \sqrt{R^2 + (2\,\pi\,n\,L)^2} = E \text{ (impressed)} \quad \text{(III.)}$$

This being merely the foregoing equation (II.) transposed.

It will be seen (Fig. 77) that in each of the three quantities—impressed volts, reactive drop, and ohmic drop, the quantity C (virtual current) occurs. Obviously C, being a common factor, may be eliminated in every case, and the quantities will then respectively represent impedance, reactance, and resistance, as shown in Fig. 78.

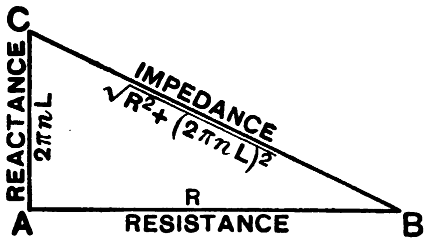


FIG. 78.—Resistance, Reactance, and Impedance.

Thus:—

$$\text{Impedance}^2 = \text{resistance}^2 + \text{reactance}^2$$

i. e.:—

$$\text{Impedance} = \sqrt{\text{resistance}^2 + \text{reactance}^2}.$$

In Figs. 77 and 78 it will be noticed that the length of $A\ C$, and therefore also the angle $A\ B\ C$, depends upon the reactive drop; or, with a given current, upon the reactance. $A\ B\ C$ is, in fact, the angle of phase.

58. TO FIND THE NECESSARY INDUCTANCE FOR A CHOKING COIL.—Suppose we have a non-inductive resistance, such as a group of forty ·35-ampere glow-lamps in parallel, for which the supply pressure is too high; by means of an adaptation of the diagram in Fig. 77 we may find out the reactance and inductance which a choking coil must have in order to reduce the supply pressure to that required by the lamps, when it is put in series with them. In Fig. 79, which should be compared with Fig. 77, we take the side CB to represent the supply pressure, or in other words the volts impressed on the circuit. Then AB is the P.D. required at the lamp terminals, otherwise the ohmic drop, while AC stands for the P.D. at the choking coil terminals, *i.e.* the reactive drop, assuming that the ohmic resistance of the choker is negligible. We thus get the following relation:—

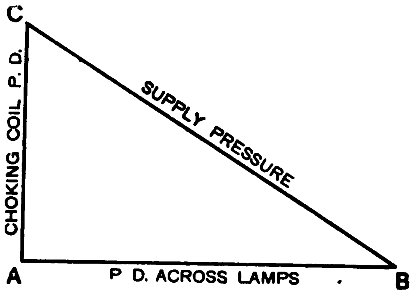


FIG. 79.—Supply Pressure and P.D.

Supply pressure^2 = (Lamps P.D.)^2 + (Choker P.D.)^2.

If the supply pressure is 240 volts at 60 $\sim$, and the lamps are 200 volt ones, and the choker P.D. required is called x,

We have:—

$$240^2 = 200^2 + x^2$$

$$i.e. \quad x^2 = 240^2 - 200^2$$

$$x = \sqrt{240^2 - 200^2}$$

$$= 133 \text{ volts.}$$

The circuit may be diagrammatically represented as in Fig. 80, L being the group of lamps and C the choking coil. The reader will probably be puzzled to find that the choking coil P.D. is greater than, instead of being equal to, the difference between the circuit pressure and that required by the lamps. This is owing to the fact that the choking P.D. lags behind the other. The case we have taken is a simple one only, where the load (*i. e.* the lamps) has no inductance, and where the choker is assumed to have little or no resistance. Generally, however, the load,

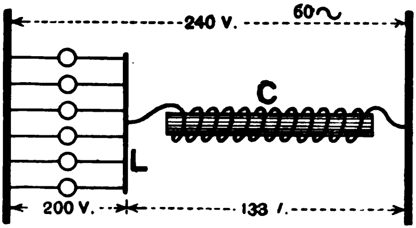


FIG. 80.—Choking Coil Circuit.

as with arc lamps, has considerable inductance, and the resistance of the choker cannot always be neglected, so that the calculation is less simple. However, to proceed with the example, having found that the necessary choking P.D. is 133 volts, the question now is to find what inductance the coil must have.

The current required by the lamps is 14 amperes. The reactive drop in the choker will then be made up as follows:—

$$\begin{aligned} 133 &= 2\pi n L C \\ &= 2\pi\, 60\, L\, 14 \end{aligned}$$

Thus its inductance $L = \dfrac{133}{2\pi \times 60 \times 14}$

$= \cdot 025$ henry.

59. Power in Alternating-Current Circuits.—The power in a direct-current circuit is obtained by simply multiplying together the pressure and the current, or—presuming the circuit has no back E.M.F. in it—the square of the current and the resistance; the product in either case representing watts (Chap. *II.*).

It might be thought that by taking the product of the virtual volts and virtual amperes in a circuit we should obtain the actual power developed. Such would be true in a sense, but the product would represent *useful power* only when the current was in phase with the E.M.F., the product in question being in all cases the *apparent power* or *apparent watts.* The phase difference or angle of lag or lead (§ 56) has to be taken into account, and the greater this is the less is the power actually being developed in a circuit with a given virtual pressure and current. In fact, if the phase difference is very great, *i. e.* if there is a large amount of either inductance or capacity in a circuit of comparatively low resistance, we may have what is known as a nearly *wattless current,* the *true power* or *effective watts* being far less than the *apparent power* or *virtual watts.*

The idea of a "wattless current" is difficult to grasp. If there be any current at all, it is not easy to understand why it cannot do some useful work. But when it is remembered that a flow of electricity—as of water—must have pressure behind it to enable it to do work, and when we are dealing with alternating pressure and flow, and can

conceive that they may be more or less out of step with each other, comprehension becomes fairly simple.

The following analogy affords a rough but useful explanation. Let $P P$ (Fig. 81) represent a pipe filled with water (or a conductor forming a closed circuit), and W, W_1, W_2, and W_3 water-wheels to which an alternating movement may be given by means of the handles h, h, h, h. These water-wheels are to be regarded as alternators. Let W W be a fifth water-wheel, to which a reciprocating motion is imparted by the to-and-fro movement of the water in the pipe. The motion of water in the lower part of the pipe-circuit may be considered as analogous to the effective current, and the consequent movement given to W W the effective power.

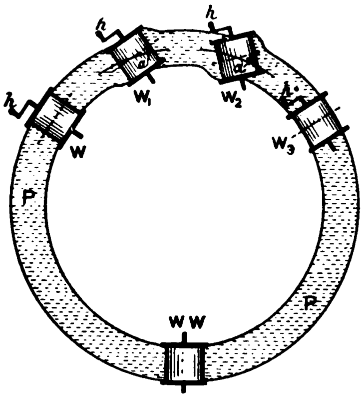


FIG. 81.—Wattless Current.

We will first consider a case where there is no phase difference—that is, when the water-motive force of W acts directly in line with the circuit, as indicated by the dotted line. Here the virtual E.M.F. of W may be said to represent also the effective E.M.F., and the virtual current or motion given to the water by W to equal the effective current operating W W. Then the apparent or virtual watts (*i. e.* virtual E.M.F. × virtual current) will also represent the true or effective watts (power given to W W).

To illustrate the effect of a small phase difference, we will next consider the water-wheel as placed slightly skew with the circuit, as at W_1; the angle of lag (or lead) being represented by the angle a between the two lines. Supposing the frequency and virtual E.M.F. of W_1 to be the same as in the first case (W), the virtual current or actual movement of electricity (water) immediately about W_1 will also be the same; but as part of the pressure will be uselessly employed in driving the water against the sides of the pipe, the repelling effect of which may be looked upon as analogous to the counter E.M.F. of reactance, the effective pressure and also the effective current about W W (the product of which is the effective or true power) will be less. The backwash from the sides of the pipe is thus analogous to wattless current.

If there be a still greater phase difference, as at W_2, though the virtual E.M.F., virtual current, and therefore also the virtual power, be the same as in the first case (W), the effective power will be still further lessened.

If the phase difference be 90°, as at W_3, where the water-wheel is placed at right angles with its most effective position; we may suppose that the current will be perfectly wattless, *i.e.* that there will be no useful power developed, and consequently no movement of W W.

The above explanation is rather weak, but is perhaps better than none at all; for the reader must get some idea, however vague, that a more or less "wattless current" can exist.

A virtual current is the actual flow of electricity as measured at the terminals of a circuit, and, depending on the conditions of the latter, a certain proportion will be

available for useful work (effective current), while the remainder is ineffective. It must be borne in mind that a wattless current is only wattless so far as its power of doing *useful* work is concerned. A current, whether "wattless" or not, will develop a proportionate amount of heat in, or a proportionate magnetic field around those parts of the circuit in which it happens to be flowing.

The "wattless current" is objectionable in central-station work for two reasons: *firstly*, because it loads up the armatures of the alternators, causing heating and reducing the useful load that may be put upon each; because the power developed with a given E.M.F. is limited by the maximum current the conductors in the armature coils can carry. *Secondly*, owing to the watts lost in the cables and conductors through which the "wattless current" flows. Although the current is wattless so far as any use that may be made of it is concerned, there still remains the loss of power due to ohmic resistance, the fall of pressure in a cable carrying a given current depending solely on the resistance, taking into account, of course, the reduction in useful area due to conductor impedance (§ 53).

Thus :—

$$\text{Pressure drop} = \text{resistance} \times \text{current}$$
$$\text{and watts lost in conductors} = \text{pressure drop} \times \text{current,}$$

the "current" being that measured on an ammeter connected to the cable in question, and therefore the virtual current.

In addition to the foregoing matters, a lag (or lead) in phase of the current sets up a troublesome reaction between the field-magnets and the armature-coils, tending

to weaken the former, and this necessitates an increase in the exciting current if the impressed virtual E.M.F. is to be maintained.

60. POWER IN ALTERNATING-CURRENT CIRCUITS (*cont.*). —The formula for the power in an alternating-current circuit is as follows :—

$$\text{(True or Effective) } P\,W = E^v\,C^v \cos\lambda$$

where $P\,W$ stands for power (in watts), E^v for virtual electro-motive force, C^v for virtual current, and λ for the angle of lag or lead.[1]

On reference to the table of cosines in Chap. *IV.*, it will be seen that for an angle of no degrees the cosine value is unity, or 1. Thus, in the formula above, if the current and pressure are in phase—*i.e.* if there is no phase difference (angle of lag or lead)—the true or effective watts may be obtained by simply multiplying together the virtual volts and virtual amperes, as mentioned in the preceding paragraph.

Thus :—

$$\begin{aligned}\text{True or effective watts} &= E^v \times C^v \times \cos 0^\circ \\ &= E^v \times C^v \times 1 \\ &= E^v \times C^v\end{aligned}$$

As the phase difference increases, the cosine values

[1] λ = Greek l (*lambda*), used for lag or lead values. Cos λ signifies the cosine of any angle λ. The cosine of angle a (Fig. 61), for instance, is the ratio of the adjacent side $B\,E$ to the hypotenuse $B\,D$, or $\frac{BE}{BD}$. The cosine value of any angle may be obtained direct from tables, such as that in Chap. *VI.*

decrease below unity; thus cos 10° = ·985, cos 30° = ·866, cos 80° = ·173, cos 90° = ·000; and the true watts become proportionately less than the apparent watts. Thus, supposing the phase difference $\lambda = 60°$, the true watts will only be half the apparent watts, for cos 60° = ·5. It will thus be seen how important it is to keep the phase difference as low as possible.

In practice, λ cannot be worked out directly with any degree of accuracy, for it varies with every variation in the conditions of the circuit, and also with the frequency. It can, of course, be calculated for any given case, but it is not a fixed or constant quantity. The true watts may be ascertained by means of a non-inductive wattmeter (Chap. *VII.*).

The apparent or virtual watts put into a circuit feeding arc lamps, motors, or other inductive apparatus through transformers, as calculated from the indications of a voltmeter and ammeter at the station end, may be greatly in excess of the actual power conveyed to the lamps, etc., *i. e.* these indications may give the idea that a far larger number of consuming devices are in circuit than is actually the case, owing to the excessive reactance in the transformer circuit.

The following record of actual observations furnishes an instructive example. The virtual current passing into and out from an alternator was 44 amperes, and the pressure 2050 volts. The exciting current for a corresponding non-inductive load would have been between 50 and 55 amperes, at about 80 volts; but this had to be increased to from 75 to 80 amperes in order to maintain the 2050 volts pressure at the alternator terminals. By tests made

with a wattmeter, which measures true power, it was found that the latter was only 56,000 watts.

Thus :—

$$\begin{aligned} \text{Apparent watts} &= 2{,}050 \times 44 \\ &= 90{,}200 \\ \text{and} \quad \text{True watts} &= 56{,}000 \end{aligned}$$

Consequently the ratio between the true and apparent watts, which is termed the *power factor*, was in this case $\frac{56{,}000}{90{,}200} = \cdot 62$.

To keep this power factor as near unity as possible is thus one of the chief problems in alternating-current distribution.

When transformers are feeding non-inductive circuits, such as glow-lamps, the reactance due to the former is less than when they are principally supplying arc lamps or motors, and is diminished as the non-inductive load is increased.

It is here that the question of the introduction of capacity (in the shape of condensers) to reduce the lag crops up; but, though most engineers are familiar with the theory of their application, it is as yet a moot point as to whether the cost and upkeep of the condensers, as well as the power lost in them, would not exceed in value the saving of power effected by their use (§ 33). The loss of power in a condenser is principally due to a phenomenon known as *dielectric hysteresis,* which is somewhat analogous to magnetic hysteresis, and which was partly explained in § 40. The rapidly alternating charges in a condenser connected up in an alternating-current circuit may be said

to cause alternating polarization of the dielectric, and consequent heating and loss of energy.

On the other hand, if the phase difference is due to excessive capacity in the circuit, the introduction of inductance will neutralize it.

61. POLYPHASE CURRENTS.—The kind of alternating current so far dealt with in this chapter is that known as the *single-phase* or *monophase current*. There are other kinds of alternating current called *polyphase currents*, which

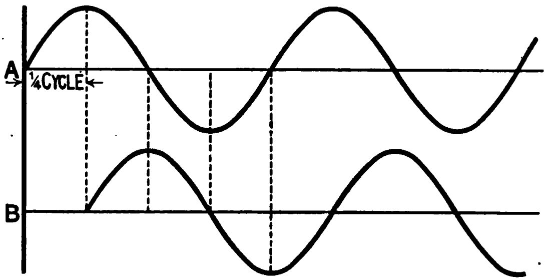


FIG. 82.—Two-phase Current.

may be compared roughly with two (*diphase*), three (*triphase*), or more simple alternating currents set up in distinct circuits, and lagging one behind the other. Such currents are specially adapted for power distribution by means of large motor generators, and for ordinary motive-power work.

As is explained in the next chapter, a 2-phase alternator is wound with two distinct sets of coils, which are connected up to two distinct circuits. These circuits lead the currents to two sets of coils on the motors, and produce therein what is known as a rotating magnetic

field. Three-phase alternators and motors are wound with three sets of coils, and the currents set up circulate in as many circuits (§§ 65, 139, etc.).

In Fig. 82, *A* and *B* represent the two circuit wires carrying the 2-phase currents, the latter being indicated by the sine waves. From this it will be seen that the second current is a quarter of a period or 90° behind

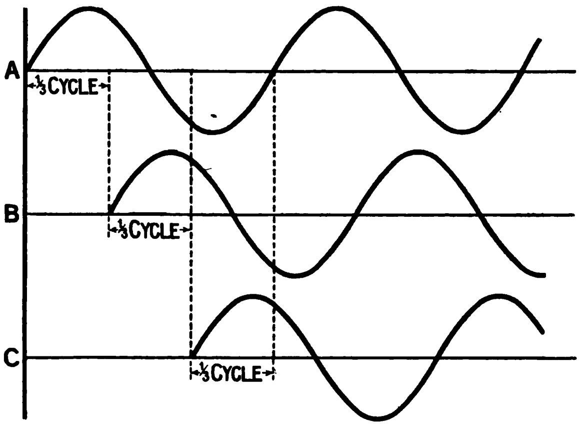


FIG. 83.—Three-phase Current.

the first. Thus when the first or 'A' current reaches its maximum in one direction, the second or 'B' current is just starting; and when the former reaches its maximum in the other direction the latter is just reversing, and so on. In other words, when either of the currents is at the top of its wave, the other is just reversing. Fig. 83 represents a 3-phase circuit, the three currents *A*, *B*, and *C* being one-third of a period or 120° apart in phase.

The two wires *A* and *B* in Fig. 82, and the three wires *A*, *B*, and *C* in Fig. 83, are those which lead the currents from the generator to the motors, etc., transformers being sometimes interposed. Besides these, either one or two return conductors are necessary with 2-phase, and sometimes one with 3-phase systems.

Apart from the merits of polyphase motors, which are alluded to in § 135, the great advantage of the 3-phase system lies in the fact that the total weight of copper required for the transmission of a given amount of power is one-fourth of that which would be necessary were single-phase working adopted. Two-phase working is rather less satisfactory than 3-phase.

The advantages of polyphase currents are being more fully appreciated by engineers in this country every day, and their use is rapidly extending.

CHAPTER XI.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Explain simply and briefly why the "curve" (Fig. 31) does not represent a real alternating current.

2. Contrast the effects of capacity in a direct and alternating-current circuit respectively.

3. Show how you would illustrate the effect of inductance and capacity in an alternating-current circuit by mechanical means.

4. Think out some experiment different from those described in § 38, to illustrate the effect of inductance in cutting-down an alternating current.

5. Why is it bad suddenly to make or break a circuit having great inductance?

*6. The resistance of the primary of a transformer is only a few ohms. Why is it that an alternating E.M.F. does not send a very large current through such a low resistance?

7. What is a choking coil? Why will it not choke a steady continuous current? [Ord. 1896.]

*8. Name some of the uses of choking coils, and sketch an arrangement of the kind.

9. What are the relative advantages of choking coils and resistances for "dimming" glow-lamps in an alternating-current circuit?

10. Define the terms — conductance, resistance, reluctance, inductance, reactance, and impedance.

*11. How could you tell which of the following were in a room inaccessible to you, if wires therefrom were led to you?—(*a*) a resistance, (*b*) a primary battery, (*c*) a secondary battery, or (*d*) a choking coil.

12. Explain what is meant by the statement that in an inductive circuit an alternate current is out of phase or step with the E.M.F. [Ord. 1896.]

*13. State Ohm's law and say whether it applies accurately to varying or alternating currents as well as to steady currents. If not, why not? [Prel. 1902.]

14. If a solenoid has a resistance of R ohms, and you send a continuous current of C amperes through it under a pressure of E volts, show that the product of volts and amperes equals the product of the square of the current multiplied into the resistance. Explain why this relation does not hold good for alternating currents. [Ord. 1892.]

15. Why should alternate current mains be either concentric or laid close together in the same channel? Has any such precaution to be adopted with mains carrying a *rectified* alternate current? [Ord. 1897.]

16. Calculate the number of (alternating) volts needed to drive an alternating current of 10 (virtual) amperes through a choking coil having a coefficient of self-induction of $\frac{1}{100}$ henry, the frequency being taken at 80 periods per second. [Ord. 1896.]

17. A choking coil is required for an arc lamp, run from a 100-volt 50-frequency circuit, and taking 15 amperes at 35 volts. How would

you construct such a coil, and for what pressure between its terminals should the coil be designed? [Ord. 1902.]

18. What is meant by impedance? If the self-induction of a circuit be 0·1 henry, and its resistance 10 ohms, at what frequency will an increase of 1 per cent. be more important than a diminution of 50 per cent. in the resistance? Prove that, when very high frequency alternating currents are employed, the self-induction of even a straight piece of wire is more important than its resistance. [Ord. 1900.]

19. An alternator, consisting of an armature with ten coils and a field-magnet with ten pairs of poles (a N. pole on one side of the field facing a S. pole on the other), is running at 1000 revolutions per minute. If the potential difference between the armature terminals is 100 volts, and the outside circuit consists of a solenoid having a resistance of 5 ohms and an inductance of 0·01 henry, what is the current? [Ord. 1898.]

CHAPTER XII.

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.); and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

*62. ALTERNATORS.—An *alternator* or *alternating-current generator* or *alternating-current dynamo* is a machine which furnishes an alternating current. An elementary alternator and its action were described both in Chap. *VIII.* and in § **42**. Practical alternators have, in most cases, multipolar fields composed of 10, 20, 30, 40, or more poles. One exception to this is the Parsons alternator (§ 74), which is a 4-pole machine.

*63. CLASSIFICATION OF ALTERNATORS.—According to

the kind of current they give out, alternators are of three principal classes: viz. those which generate ordinary or monophase alternating currents, and those which generate diphase or triphase currents respectively (§ 60).

This classification may be set forth thus :—

Alternators.	(i.)	Uniphase or monophase or single-phase.	
	(ii.)	Diphase or two-phase.	Polyphase.
	(iii.)	Triphase or three-phase.	

We may term an alternator a *uniphaser*, *diphaser*, *triphaser*, or *polyphaser*, according to its type; and the three first terms might be otherwise written :—*phaser*, *2-phaser*, *3-phaser*, the former name being a suggestion of the writer's. As will be explained presently (§ 65), the essential difference between these three kinds of generator lies in the winding of the armature only; the form of the machine, and the arrangement of the field-magnet, being practically the same in all three cases.

*64. MONOPHASE ALTERNATORS.—The action of the ordinary multipolar monophaser may be fairly well grasped from Fig. 84. Here C_1, C_2, C, C represent the armature-coils, and N_1, S, N, S the field-poles; the former being fixed and the latter rotating, though the reverse is often the case. The coils are placed end on to the poles in the figure, so that their connection together may be clearly seen. In such a machine the number of armature-coils and field-poles is generally equal. C, C are either joined all in series, and the two ends connected to terminals as at T', T; or they may be joined-up in two, three, or

more sets in parallel. For instance, if *T*, *T* be connected together to form one terminal, and a second connection be made at *T′*, the coils being thereby arranged in two parallel sets, the E.M.F. of the machine will be reduced to one-half, while its current will be doubled. In fact, were it necessary, the armature-coils of an alternator might be treated as the cells of a battery, and arranged in any parallel-series combination to suit requirements. Other things being equal, the greater the number of coils in series the greater the E.M.F. of the machine. When the armature rotates, collector-rings take the place of the terminals.

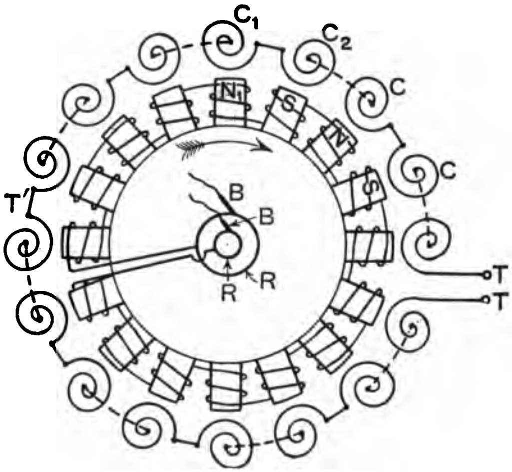


FIG. 84.—Connections of a Single-phase Alternator.

It will be clear that the currents induced in those coils opposite N. poles will be in the reverse direction to those induced in the coils facing S. poles; so that it is necessary for the coils to be connected together alternately right-handedly and left-handedly (as indicated in the figure), in order that the currents being induced in them at any given instant may all unite and flow the same way.

As the field-poles move on in the direction shown by the curved arrow, the coils now facing N. poles will have S. poles in front of them, and *vice versâ*, the current in all of them being reversed simultaneously. Thus as the poles move round in front of the coils, a monophase alternating current, similar to that described in § 42, will be delivered to the external circuit. The direct current (exciting current) for the revolving field magnet is led in through the brushes *B*, *B*, and contact or slip-rings *R*, *R*. The number of complete reversals of the current during one revolution of the machine, will be equal to the number of pairs of poles (or in other words to half the number of poles) on the field-magnet. Thus in Fig. 84, while N_1 is in front of C_1 the current will be in one direction, and will reverse when N_1 comes opposite C_2. Thus while N_1 is passing these two coils the current makes one complete period.

The frequency of an alternator is thus equal to half the number of magnet-poles multiplied by the number of revolutions per second (§ 44). As mentioned in § 43, the frequencies of alternators in English generating stations vary from about 25 to 100 ∼.

The explanation of the induction of currents in the armature-coils when the field-poles pass in front of them will be found in Chap. *IV*.

*65. TWO- AND THREE-PHASE ALTERNATORS.—In a 2-phaser there are, generally, twice as many armature-coils as field-poles; the former being arranged in two distinct sets or circuits, and placed alternately round the frame. This is represented in Fig. 85, showing half the ring of armature-coils and field-poles, where *A*, *A*, *A*, etc. are

the coils which are connected together in one set, and

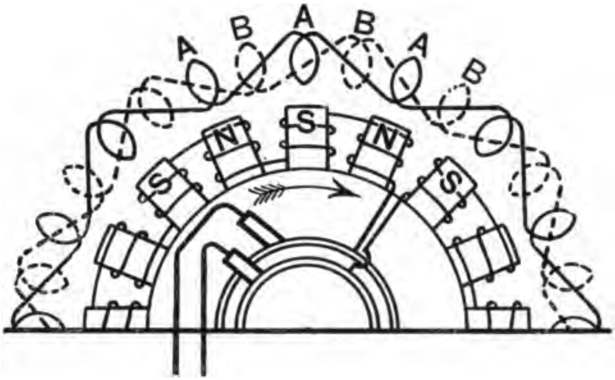


FIG. 85.—Connections of a Two-phase Alternator.

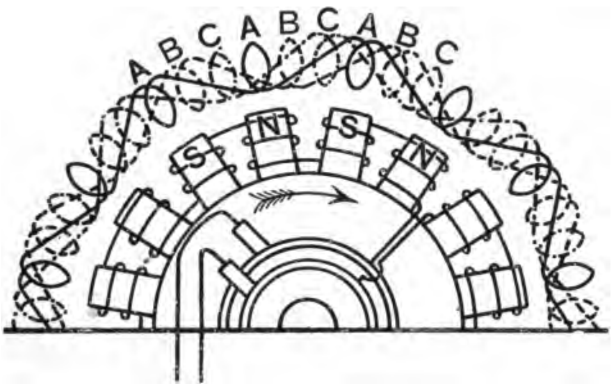


FIG. 86.— Connections of a Three-phase Alternator.

B, B, B, etc. those of the other set, all the coils being of the same size. Now as the F.M. rotates in the direction shown

by the arrow, it will be obvious that the currents in *A, A, A* will be induced a little before those in *B, B, B,* so that although the alternating current in *A* circuit will be of the same pressure and frequency as that in *B* circuit, the two will not be in step.

As explained in § 42, an ordinary or single-phase current may be represented by a wavy line of the form given in Fig. 59. Similarly Fig. 82 denotes a diphase current, the first or *A* current being a quarter of a period or 90° in advance of the *B* current.

Fig. 86 gives a diagram of the arrangement of the coils and poles of a triphaser, there being in this case three sets of armature-coils, *A, A, A, B, B, B,* and *C, C, C.* Here the currents in *A, A, A* will be a little in advance of those in *B, B, B,* and the latter a little in advance of those in *C, C, C.* In fact, each current will be 120° or one-third of a period in advance of the other, as depicted in Fig. 83.

The differences between single-, two- and three-phase windings are further illustrated in Fig. 86A.

Here, at I, *s, s, s,* etc. are the slots in which the winding is laid, while 1 1, 2 2, 3 3, and 4 4 may be looked upon as four separate coils, each with one turn only in order that the figure may not be too complicated. *K, K, K* are the conductors connecting neighbouring coils, and *N, S, N, S* are the field-poles, the winding of the latter being omitted. A 2-phase winding is given at II, the coils of the two phases being marked respectively *A* and *B.* Similarly at III, *A, B,* and *C* are 3-phase windings.

Figs. 91, 92, and 93 also illustrate the three different windings, the armature-core being there viewed from the

face, that is in the direction in which the magnetic lines from the field-poles enter and leave it.

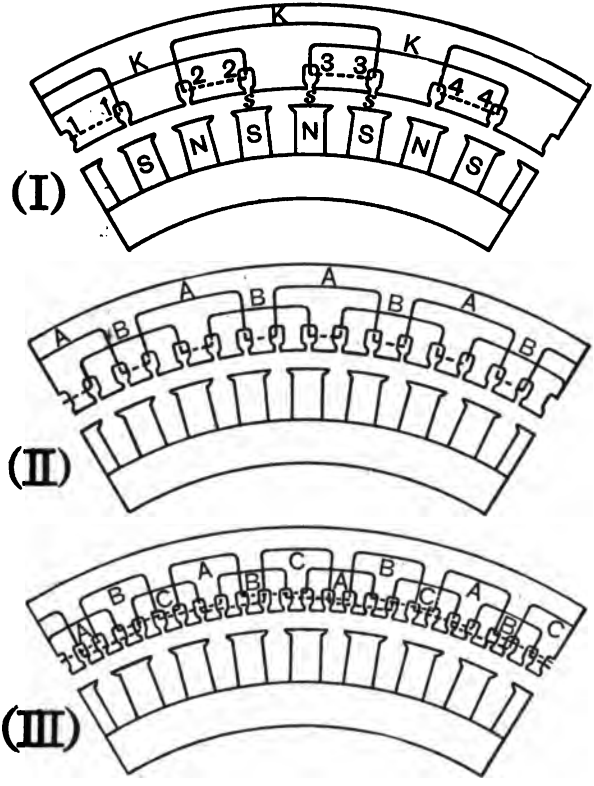


FIG. 86A.—Single-, Two- and Three-phase Windings.

The currents from a 2-phaser or 3-phaser are delivered into separate cables, anent which something is said in § 198.

*66. CLASSIFICATION OF ALTERNATORS (*cont.*).—As regards their field-magnets and armatures, alternators are divisible into three classes, any of which may be monophase or polyphase.

(*a.*) Those with fixed F.M. coils and rotating armature-coils.

(*b.*) Those with fixed armature-coils and rotating F.M. coils.

(*c.*) Those in which both armature and F.M. coils are fixed, the moving portion carrying the whole or part of the F.M. core. Such are termed *inductor alternators.*

The terms *rotor* and *stator*, originally used to designate the moving and fixed parts respectively of polyphase motors, are now frequently employed in connection with all classes of generators and motors.

Examples of class *a* are the Ferranti "copper-type," Mordey-Victoria, and Parsons Turbo machines. The Ferranti "iron-type," Johnson and Phillips, and Mather and Platt alternators belong to class *b*, and the Brush Inductor machine to class *c*. The latter type may possibly gain in favour, as obviously it is a great mechanical advantage to have both F.M. and armature-windings stationary, and a great electrical one to be able to do away altogether with collectors or slip-rings.

There is necessarily a high P.D. between the two *collector-rings* or *slip-rings* through which the brushes collect the current from the armature of a uniphase machine of class *a*; and in order to lessen the danger therefrom, in some machines they are placed at opposite sides of the armature, so that it is impossible for a man to touch both at once. In class *b* there is the advantage that the

ends of the armature are simply joined to fixed terminals, which can be easily shielded. In this case the two slip-rings which lead the current into and out from the field-windings are at such a low potential that there is comparatively little danger from shocks. With inductor machines there is the obvious advantage that there are no rings or brushes whatever to trouble about. Since in 2- and 3-phase generators there are respectively two and three distinct sets of coils, such generally have fixed armatures, many structural difficulties being thereby avoided.

*67. CLASSIFICATION OF ALTERNATORS (*cont.*).—Alternators may also be classified with reference to the form and disposition of their armature-coils.

(*A.*) A *face-coil slotted armature* is one in which each coil is placed with its plane at right angles with the direction of rotation of the alternator; or, in other words, with its side facing towards or away from the centre of the shaft, according as it is on the fixed or moving part; the conductor being embedded in slots cut in the iron core.

(*B.*) A *face-coil tunnel armature* is similar to the above, except that the conductor is threaded through holes in the core-plates formed like slots with very narrow openings. Such slots are shown at *B* in Fig. 179.

(*C.*) In a *face-coil pole armature* the coils are wound on bobbins which fit over radial projections on the core.

(*D.*) A *radial-coil armature* has flattened coils fixed edgewise to the rotating part or fixed frame, as the case may be; the ribbon-shaped conductor being wound on a non-magnetic frame or core. Such armatures are often

termed *coreless* to distinguish them from those in which the coils have iron cores.

(*E*.) A *drum armature* is very similar to that of a direct-current machine, and may be either slot or tunnel wound.

Any of the above types, except the last, may be either fixed or movable, and all are adaptable to polyphase work.

The Ferranti "iron-type," Johnson and Phillips, Brush Inductor, and Mather and Platt machines belong to class *A*. The Ferranti "copper-type" and Mordey-Victoria generators are examples of class *D*; and Parsons Turbo-generator represents class *E*. There are no examples here of classes *B* or *C*.

*68. CLASSIFICATION OF ALTERNATORS (*cont.*).—According to the method of excitation of their F.Ms., alternators are divisible into four classes, as follows :—

(*a*.) *Separately-excited alternators.*—In which the F.Ms. are excited by a separate direct-current machine, which is called the exciter; or from a battery.

(*β*.) *Separate-coil alternators.*—In which separate coils on the armature furnish the magnetizing currents, which currents, being alternating, have to be "rectified" or made continuous by means of a special commutator.

(*γ*.) *Compensated or compounded alternators.*—In which the F.Ms. are excited partly by "rectified" currents from separate armature coils (as in *β*), or from a direct-current exciter; and partly by currents from a small transformer, the primary coil of which is in the main circuit; the transformer currents having likewise to be "rectified" or commutated.

(*δ*.) *Magneto alternators.*—In which permanent magnets are used as field-magnets.

With the exception of the old-fashioned De Meritens alternators still used in France in lighthouse work, the last class is now practically obsolete, so far as electricity distribution is concerned: but very small machines of this type are used for signalling, blasting, testing and medical work, and are known as *magneto machines* (Chap. *V.*). Nearly all present-day alternators come under class *a*, examples of classes β and γ being comparatively rare, and confined to American and foreign makers.

In the following paragraphs various representative types of alternator are described. It should be remembered, however, that nearly every firm has at different times constructed machines varying very much in general arrangement and appearance. As far as possible those illustrated herein represent the latest developments of their respective makes.

69. The Ferranti "Copper-type" Alternator.—The Ferranti alternators are made in two forms:—(*a*) with stationary field and revolving armature, this being called by the makers the "*copper type*"; and (*b*) with stationary armature and revolving field, termed the "*iron type.*" These names are intended to signify that the armature of the former is a coreless one, *i. e.* without any iron; while in the latter case the coils have cores of laminated iron.

Fig. 87 illustrates the armature, and Fig. 89 the field-frame of the copper-type generator; though, by the way, the parts illustrated do not belong to one and the same machine. The method of construction of the armature, about to be described, is such that these machines can only be built for single-phase work. The armature in

Fig. 87 is one for a 500 kw. 2100-volt machine, and it

Fig. 87.—Armature of Ferranti "Copper-type" Alternator.

has 40 coils or bobbins. It belongs to the vertical-coil class mentioned in § 67. The bobbins are formed of

copper strip wound on laminated brass cores, the beginning of the winding of each being connected to the base of its core, and the other end taken to an insulated terminal shown at the bottom of the bobbin-carriers. The turns on the bobbins are insulated from one another with specially-prepared paper.

The bobbins are bolted in pairs between two brass plates called bobbin-carriers, and they are insulated from the same by mica shields or sheets, except where the rivets pass through the bobbin-core and carrier to fix the same together, and also to form electrical connection between the two bobbins mounted in the same pair of carriers. Each pair of carriers supporting its pair of bobbins is fixed on to the fly-wheel by means of bolts and nuts fitting into lugs on the outside edge of each carrier. The bolts are covered with a sheathing of ebonite, this and other precautions being taken to insulate the carriers from the rim of the driving-wheel.

The insulated terminals of adjacent bobbins mounted in different pairs of carriers are connected together with copper links, nuts, and bolts. Each pair of carriers thus forms an easily-removable unit of the alternator. These connectors are omitted from Fig. 87, but are shown at *C*, *C*, etc., in Fig. 88.

The whole armature is divided into two parallel circuits, and the common terminals of the two parallel circuits are connected to two collector-rings by copper rods insulated with ebonite. One of these rods may be seen at *R* in Fig. 87, but the collector-rings are not visible.

When the system is working with one of the poles earthed (as is the most usual case), one collector-ring

only is necessary, for the high tension pole; the other end of the armature circuit being connected directly to the fly-wheel, and the current taken through brushes pressing

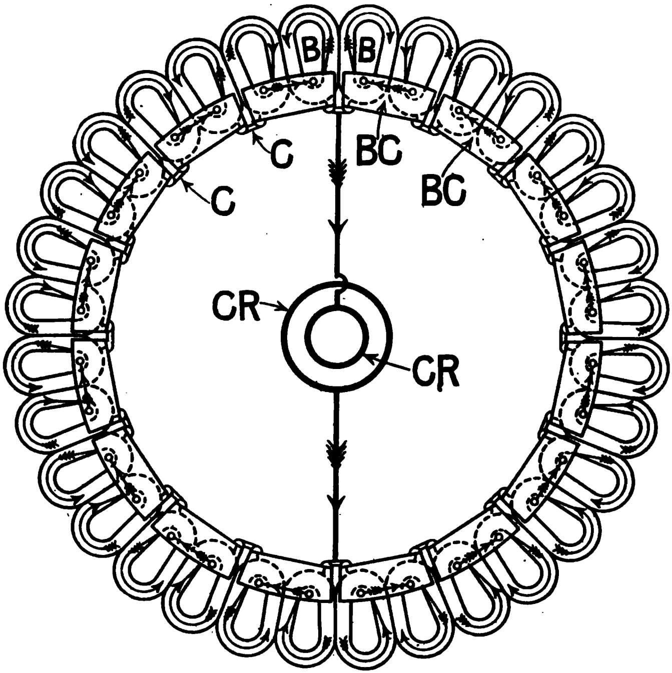


FIG. 88.—Armature Connections of Ferranti "Copper-type" Alternator.

on the shaft or boss of the wheel. In Fig. 88 a diagram of the armature and its connections is given, the path of the current round the coils, across the bobbin-carriers, and down to the collector-rings, at a given moment, being

shown by arrows. Here *B, B* are the bobbins, *B C, B C*

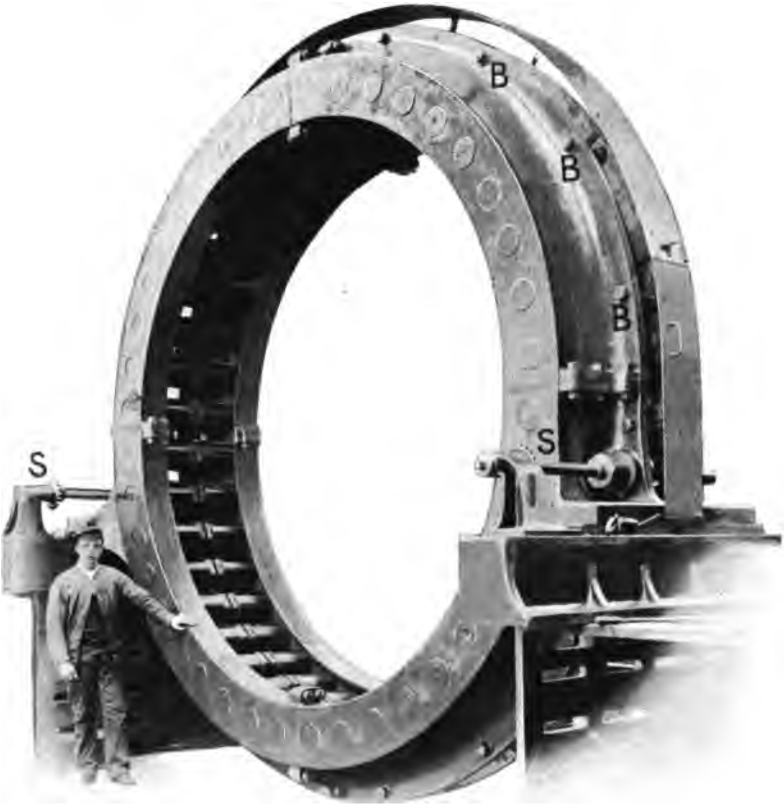


Fig. 89.—Field-frame of Ferranti "Copper-type" Alternator.

the bobbin-carriers, *C, C* the links connecting the insulated terminals, and *C R, C R* the collector or slip-rings.

The field-frame shown in Fig. 89 is that of a 650 kw. 10,000-volt machine, and has 40 pairs of poles erected in two circular frames. The latter have elbows cast on each side, these being supported by girder bed-plates. The air gap between the opposite pole faces may be adjusted by screw gear, shown at *S*, *S*, this moving the two frames apart or together. The same gear is used to open the frames widely apart for cleaning purposes. This gear consists of two horizontal shafts *S*, *S*, with right- and left-handed screw-threads cut on them, the two threads engaging respectively with the opposite halves of the magnet frame. Thus when the shafts are turned simultaneously, the two halves of the frame are brought together or moved apart as the case may be. Before this can be done, however, the bolts *B*, *B*, *B*, etc. must of course be removed. Each of the magnet-coils is composed of a single layer of copper strip or tape, wound on edge, the winding being well insulated turn from turn, as well as from the steel pole core and frame, with pressspahn.[1] The coils in each frame are connected in series, the ends of the two circuits being brought to terminal boxes; and these two circuits or rings are connected either in series or parallel, as is most suitable, to the source of excitation. The poles are alternately N. and S. round each ring, and facing poles are of opposite polarity. To prevent sparking from the armature bobbins to the metal of the pole faces, as they travel between the latter, these faces are capped all over with mica.

Fig. 90 gives a general view of an alternator of this type coupled to a compound engine. Immediately in front of

[1] See p. 134.

the figure is the exciter, which is a Parker machine similar to that illustrated and described in Chap. *IX.*, and which is rope-driven from a pulley by the side of the armature.

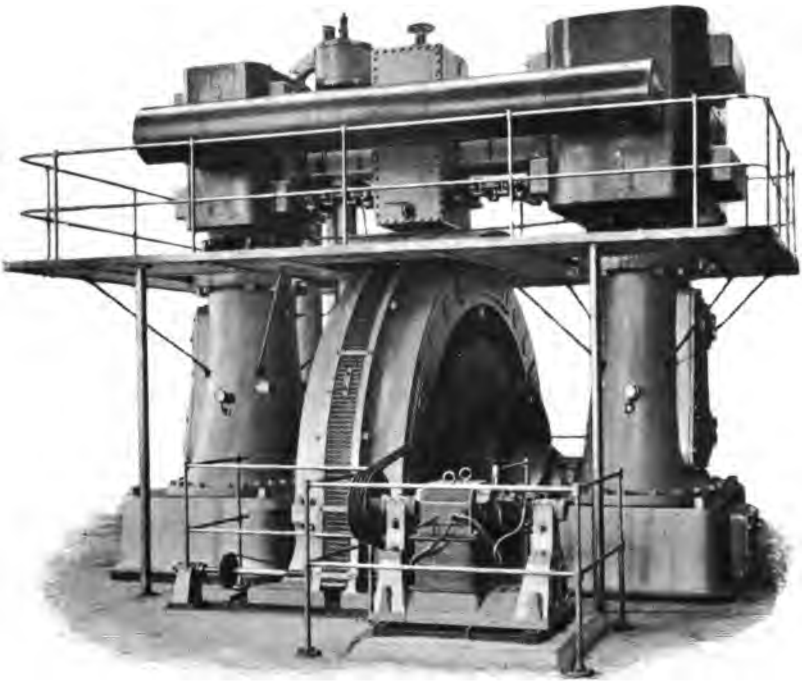


Fig. 90.—Ferranti "Copper-type" Alternator.

The screw gear for moving the two halves of the magnet frame can also be seen.

*70. The Ferranti "Iron-type" Alternator.—The armature-core of the iron-type machine consists of a ring

of sheet-iron stampings bolted to the inside surface of a

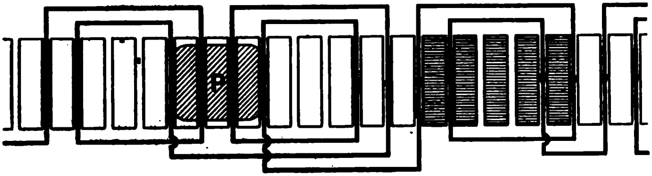


FIG. 91.—Single-phase Winding.

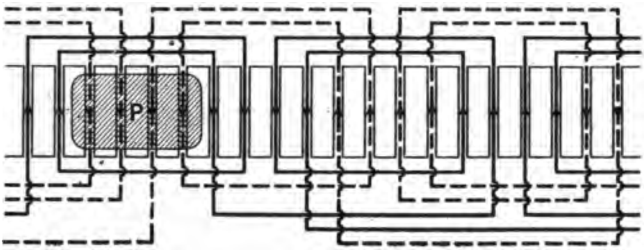


FIG. 92.—Two-phase winding.

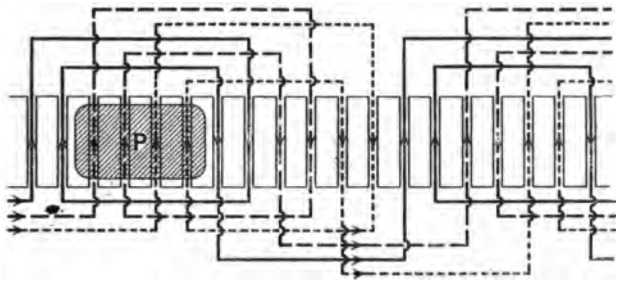


FIG. 93.—Three-phase Winding.

circular cast-iron frame, the latter having elbows cast on it for supporting the whole from the bed-plates.

The ring of stampings is built up of short lengths, with slots punched in the inner edge; the stampings being lapped one over the other, with shellaced paper between, and the whole baked together. At intervals in the width of the armature face, by means of suitable distance pieces, ventilating gaps are left; this construction being somewhat similar to that shown in Fig. 95. When the core is built up, the slots therein are carefully insulated, and the former-wound coils afterwards placed in position. The different coils round the machine are all connected in series, well-insulated terminals being provided in a suitable position.

For 2- or 3-phase work other coils are introduced, these being bent where necessary to miss the first series, and thus other circuits are formed round the machine, each circuit being separate, and having its own terminals. Figs. 91, 92 and 93 represent portions of the slotted core flattened out, with the windings shown diagrammatically. Fig. 91 depicts three coils of a single-phase winding, a certain number of slots being left vacant. It should be remembered, by the way, that in this and the other cases (Figs. 92 and 93) there are a number of turns in each slot, the number depending on the voltage required. Fig. 92 illustrates a 2-phase winding, the coils of one phase being shown in firm lines, and those of the other phase in dotted lines. A 3-phase winding is depicted in Fig. 93, the three sets of coils being differently lined. There are, however, a number of other ways of arranging these windings. The area of the rotating pole-pieces is shown in each figure at *P*, and the relative directions of the induced E.M.Fs. by arrow-heads.

In Fig. 91 the lamination of a few of the teeth is indicated.

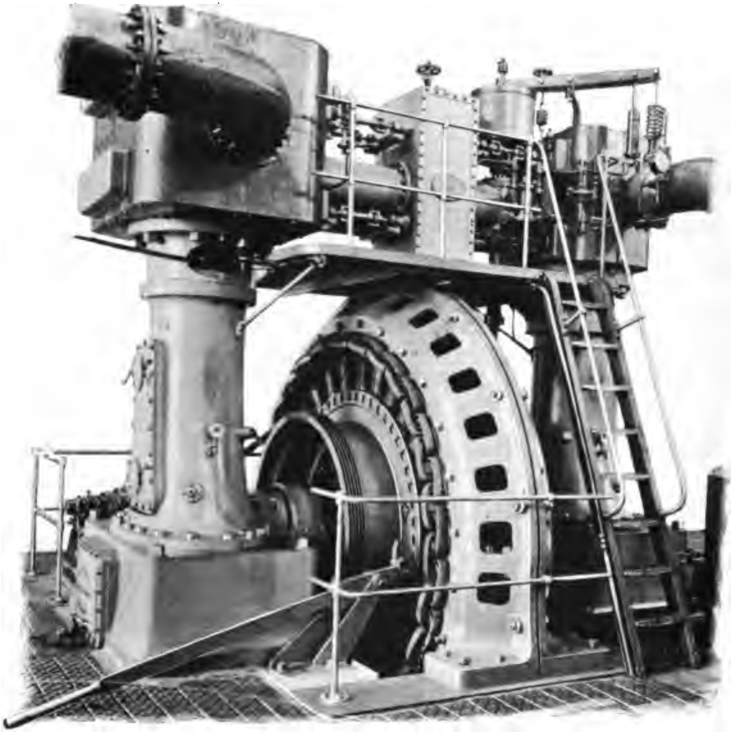


FIG. 94.—Ferranti "Iron-type" Alternator.

The field of the iron-type machine consists of a series of steel poles mounted radially on the rim of the fly-wheel. Around each pole lies a field-coil, which is of

copper strip wound edgewise, each turn being separated from the next with pressspahn, and the whole well insulated

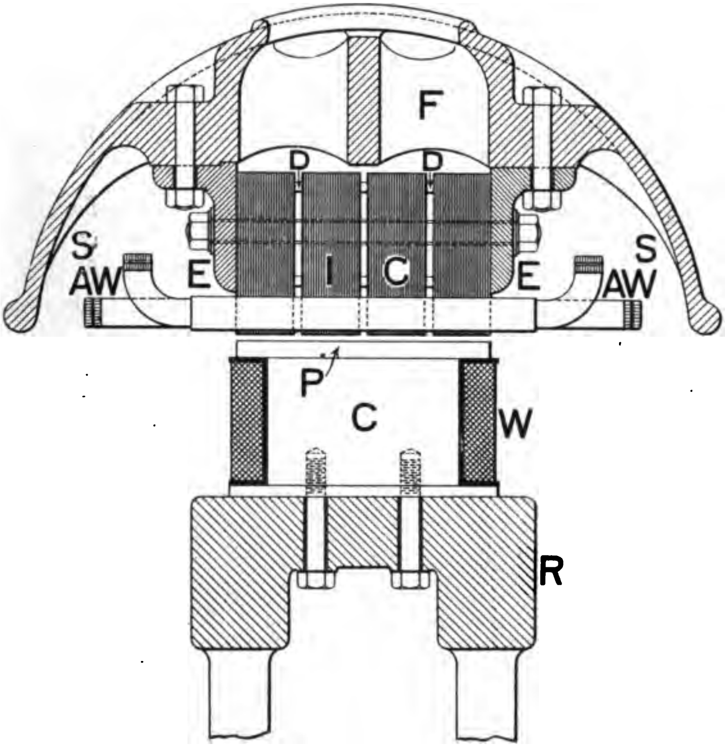


FIG. 95.—Section of New Ferranti "Iron-type" Alternator.

from pole and wheel. The field-coils are connected in series, and, by means of copper rods passing through insulating sleeves in the rim of the wheel, they are joined

up to two collector-rings, which are connected through brushes to the exciter.

Fig. 94 shows the present form of iron-type machine, coupled to a compound engine. As will be noticed, the particular machine illustrated is wound for 2-phase work, the ends of the coils being very prominent. Behind the left-hand crank-case of the engine is the exciter, this being rope-driven from a pulley at the side of the field-magnets.

The arrangement of the armature core and coils, as already described, may be understood from Fig. 95, which gives a section of the very latest pattern of iron-type alternator, this being somewhat different from that in Fig. 94, especially as regards the fixed outer frame supporting the core and coils. Here *F* is the outer cast-iron ring or frame, the sides of which, *S, S*, form shields for the ends of the armature windings *A W, A W*. Thus in this new type the ends of the coils do not show outside as in Fig. 94. The laminated iron core *I C* is separated by distance pieces *D, D* to form ventilating passages, and is bolted in sections between end plates *E, E*, which in their turn are bolted at each side to *F*. *R* is the rim of the driving-wheel, one of the magnet cores *C*, with its winding *W*, and pole-piece *P* being shown bolted thereto.

71. THE MORDEY-VICTORIA ALTERNATOR.—In this alternator, which is made by the Brush Electrical Engineering Co., the F.M. rotates and the armature is stationary, the latter being of the radial coil type. Fig. 96 illustrates the design of the ordinary-sized machines.

Over the centre of the shaft (Fig. 98), and keyed to it, is a short cylinder of iron round which is wound the single

exciting or F.M. coil of the machine. This cylinder consequently forms the core of the F.M. At each end of this core is attached a large casting, carrying claw-shaped

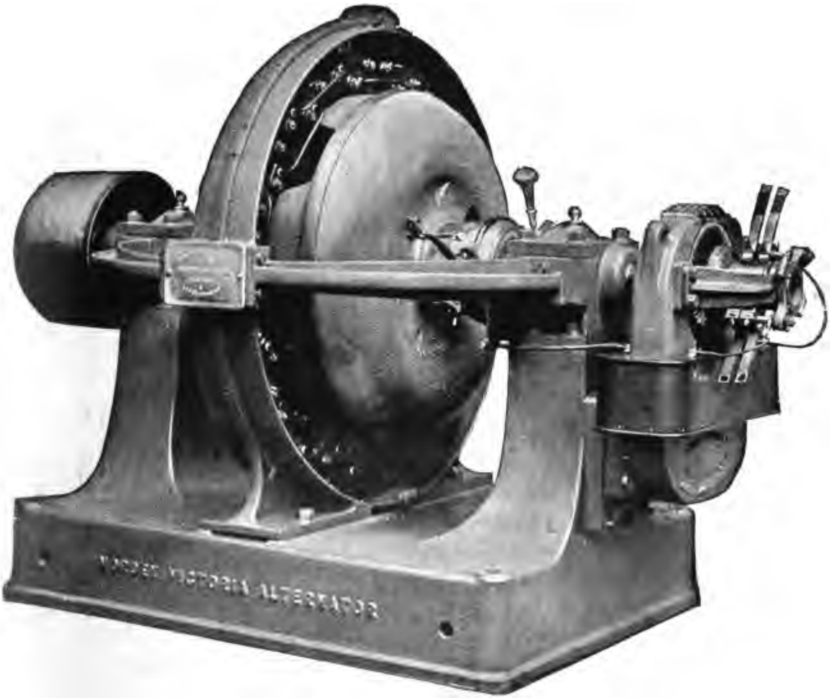


Fig. 96.—Mordey-Victoria Alternator.

pole-pieces which bend over and almost enclose the coil. The claw pole-pieces on one side come opposite those on the other, sufficient space being left between for the passage of the armature-coils. All the poles on one

side are N., and all those on the other side S. Fig. 98 illustrates the earlier form of F.M. In more recent designs, as in Fig. 96, the claws on each side are united by a thin external web, so as to prevent churning of the air. For this same reason, the spaces between the spokes of the rotors of many large alternators are cased in with wood.

FIG. 97.—Mordey-Victoria Alternator (Armature Frame).

The number of claws or pole-pieces depend upon the speed and frequency of the machine. Thus some large machines have had as many as sixty pairs of pole-pieces. In these larger machines the general shape of the F.M. is different from that illustrated in Fig. 98, but the principle is the same. The ends of the F.M. coil are connected with insulated rings on the shaft (Fig. 98), through which, by means of brushes, connection is made with the exciter, the armature of which is often fitted on an extension of the shaft (Fig. 99). It will be seen that this

shaft runs in a grooved bearing, collars being turned on one end of it to prevent end-play, or longitudinal movement in the bearings, as the clearance between the faces of the pole-pieces and armature-coils is necessarily very small.

The arrangement of the armature is shown in Fig. 97.

Fig. 98.—Mordey-Victoria Alternator (Field Magnet).

The coils are of thin copper ribbon wound on cores of porcelain or enamelled slate, the different turns being separated by insulating tape. Each coil is fixed in a German silver bracket cased in ebonite, German silver being used on account of its high resistance, the tendency of eddy currents to be set up in the brackets by the revolving fields being thereby diminished. These brackets

are securely bolted to the outer frame, and they carry the terminals through which the coils are connected with one

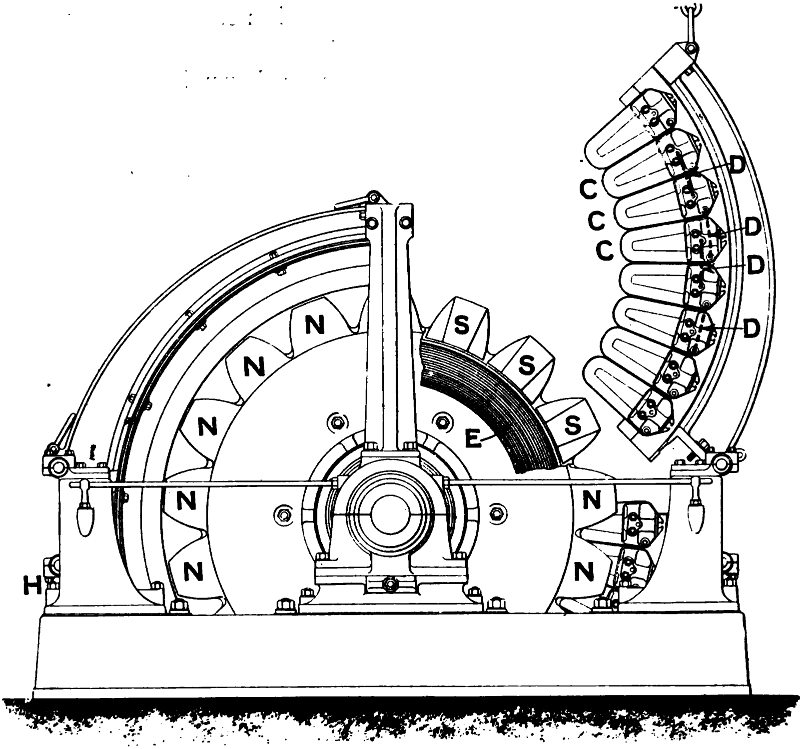


FIG. 99.—Mordey-Victoria Alternator (Part Section).

another. At the sides of the armature frame are square terminal boxes, through which connection is made with the armature. The figure shows the armature-coils all in

series, and the ends terminate in the right-hand terminal box, the left-hand one being unused. If the two halves of the armature were joined in parallel, as is sometimes done, both terminal boxes would be employed.

The output of the machine shown is 75,000 watts, the maximum virtual E.M.F. 2000 volts, and the speed 500 rev. per minute; its height being about five feet. These alternators are made in sizes varying from 12 to 300 kw., and in the larger sizes the exciters are separate.

Fig. 99 gives a side view of one of the latest forms of Mordey-Victoria alternator. Here it will be observed that the top half of the frame is in two portions, each of which is hinged so that it can be raised to enable the coils to be got at. The two parts of the bottom half of the frame are similarly hinged as at *H*. A portion of the field-magnet is given in section, showing the exciting coil *E*, and pole-faces *S*, *S*, *S*. *N*, *N*, *N*, etc. are the outsides of the poles on the near side of the magnet frame. The coils *C*, *C*, *C* are rather narrower and longer than those in Fig. 97, and the connectors between them are not shown, but their position is indicated by the dotted lines *D*, *D*, *D*, etc. Face and edge views of a coil are given in Fig. 100. Here *C* is the outer cast-iron frame, to which is bolted the brass flange-ring *B*, which supports the German silver coil-bracket *G*, to which the coil itself is clamped between ebonite insulating pieces *E*, *E*. *P* is the porcelain coil core, and *W*, *W*, *W* the winding, the ends of which are joined up to the connectors at *J*, *J*. This winding, which is better shown in Fig. 97, consists of copper strip taped and varnished, the outer edge at *O*, *O*, *O* being faced with mica, so that the sides of adjacent coils shall be well

insulated one from another. The whole is bound to the core by varnished string *V, V, V.*

The output of the particular machine illustrated in Fig. 99 is 95 amperes at 2100 volts (about 200 kw.), the speed being 353 r.p.m.

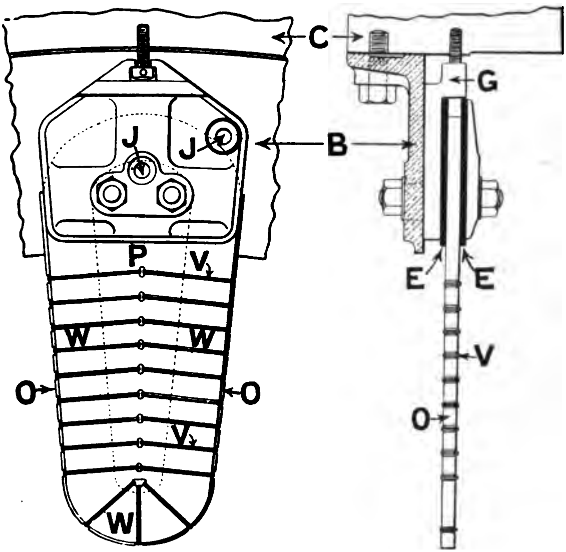


FIG. 100.—Mordey-Victoria Alternator (Armature Coil).

72. THE BRUSH INDUCTOR ALTERNATOR. — This machine, as its name indicates, belongs to the inductor class, both the armature and field-windings being stationary. It is suitable for much larger outputs than the Mordey-Victoria alternator built by the same makers, and, unlike the latter, can be easily wound for any phase.

The external appearance of this generator may be gathered from Fig. 101.

The armature is of the face-coil slotted type, the coils

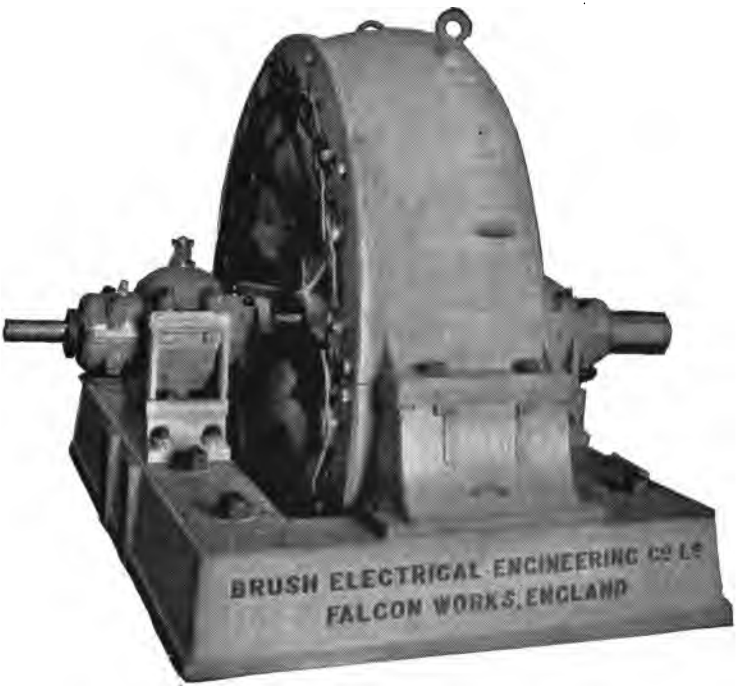


Fig. 101.—Brush Inductor Alternator.

being laid in slots cut in the laminated iron lining of the fixed cast-iron frame. There are two circles of these coils, and between them is fixed the F.M. winding, the F.M. core being the only part that rotates. The F.M. as a whole may be likened to that of the Mordey-Victoria

generator, with the difference that the poles stick out radially instead of turning in to face one another, and that the core slips round within its exciting coil, the latter being fixed. This rotating core is of cast-steel, the tips of the poles being faced with laminated soft iron. A side view of this machine, one half being in section, is given in Fig. 102. Here *F, F* is the cast-iron outer frame, with ventilating holes *V, V* therein. The slotted iron core is secured to this frame by the bolts *B, B, B*; and *S, S, S* are the slots in which the armature-coils are laid, the latter being absent. *P, P, P* are the rotating pole-tips, and *W, W* is the fixed field-winding, this being clamped in supports at *C, C, C*.

The construction of the machine, as regards the disposition of the armature and field-windings, is more clearly shown in Fig. 103. *F, F* is the cast-iron frame, *V* one of the ventilating holes therein, and *L, L* the two laminated slotted rings in which the armature-coils are placed, *E, E, E, E* representing ends of the coil windings. *F′, F′* is the fixed field-coil, which is wound in two portions, these being clamped together to a supporting ring by means of the clamps *C, C*. *R* is the rotating wheel carrying the laminated inductor poles *I, I*, and *V′* is a ventilating channel. *B′* is one of the bearings of the machine, and a front view of half of the same may be seen at *B′* in Fig. 102. The other bearing is not shown.

The output of this particular alternator, wound 2-phase, is 375 kw. at 2200 volts, the speed being 200 r.p.m.

This type of machine is specially suitable for 2-phase work, the two sets of coils being mounted on the two distinct armature core rings. For single-phase work the two

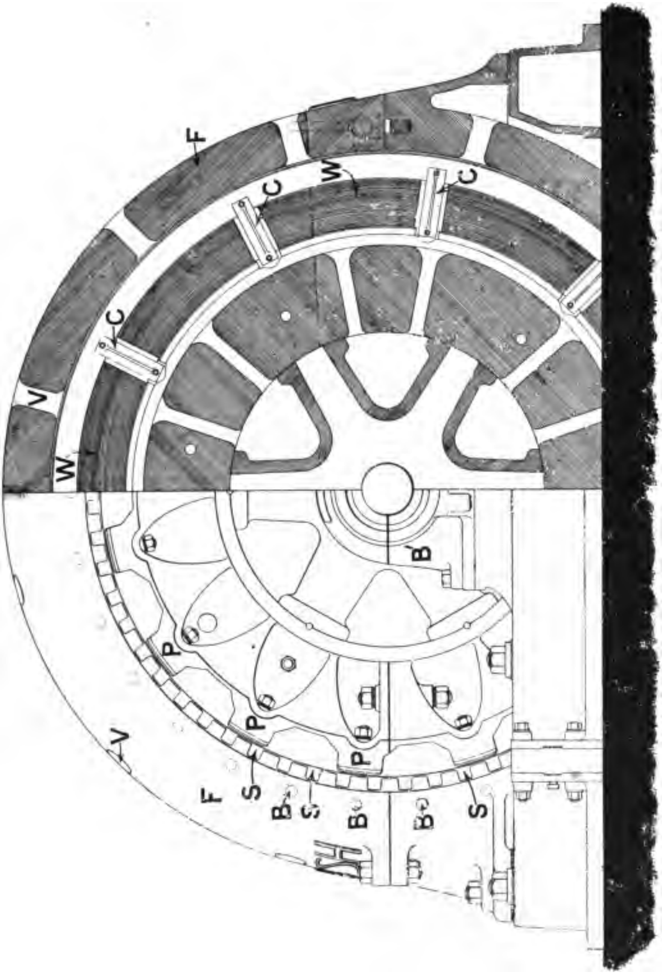


FIG. 102.—Brush Inductor Alternator (Part Section).

windings, which must then be in line with each other, would be connected either in series or in parallel, as found most convenient for the purpose required. For 3-phase

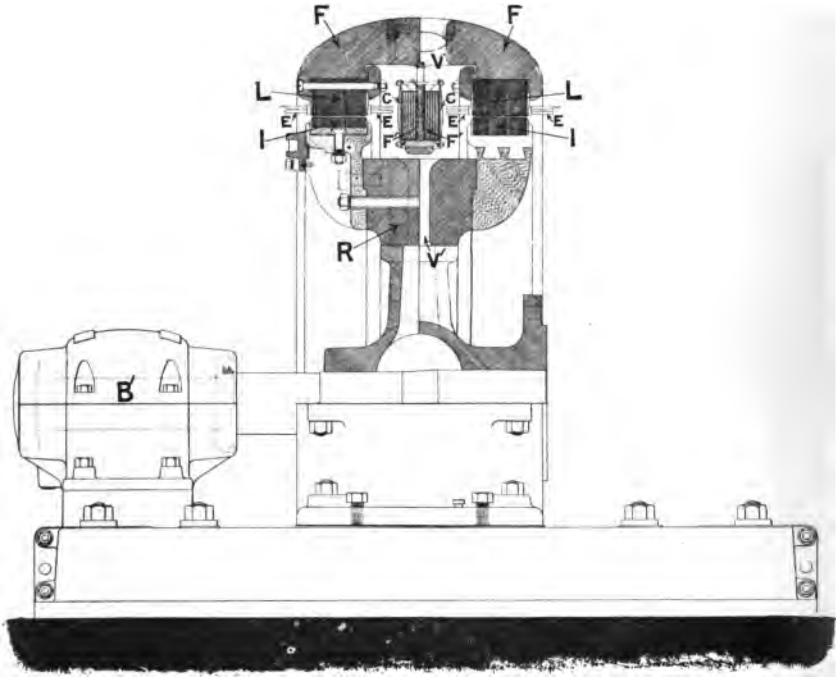


Fig. 103.—Brush Inductor Alternator (Section).

work two of the windings would be on separate sides of the machine, while the third would be partly on one side and partly on the other.

73. The Johnson and Phillips Alternator.—Like

most other firms, Messrs. Johnson and Phillips have built various forms of alternator at one time and another; one pattern having an armature like that in Fig. 104, but with

Fig. 104.—Johnson and Phillips Alternator.

a field-magnet similar to that of the Mordey-Victoria machine, except that the poles stick out radially instead of facing each other.

The machine illustrated in Fig. 104 is the latest pattern by these makers. It happens to have a 2-phase winding,

but it is, of course, easily adapted for either single or 3-phase work. It has a fixed slotted face-coil armature with removable coils; and a rotating field-magnet with radial poles, each of which carries its own exciting bobbin.

The armature-core consists of a large number of slotted segmental plates of charcoal iron threaded on to bolts passing through and secured in the strong cast-iron circular shell or outer frame: and the armature-winding is embedded in slots round the interior circumference of the core. The conductors consist of wire or bars of copper (accord-

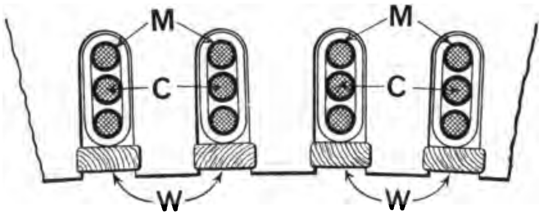


FIG. 105.—Johnson and Phillips Alternator (Section of Armature-core and Winding).

ing to the number of turns required), braided on the exterior; the slots being lined with micanite before the coils are placed in position. The ends of the armature-winding are taken into insulated terminal boxes, mounted on the front of the machine, as seen in the figure. In Fig. 105 is shown a portion of the core and a section of the windings. The conductors *C*, of which, in this case, there are three in each slot, are insulated from the latter by micanite tubes *M*, *M*, the windings being held in position by wooden wedges *W*, *W* driven down the front of each slot, which is specially shaped to receive them.

The field-magnet consists of a heavy fly-wheel to which are bolted cast-steel magnet cores carrying bobbins arranged alternately N. and S. The current for exciting the field-winding is conveyed by a double set of brushes

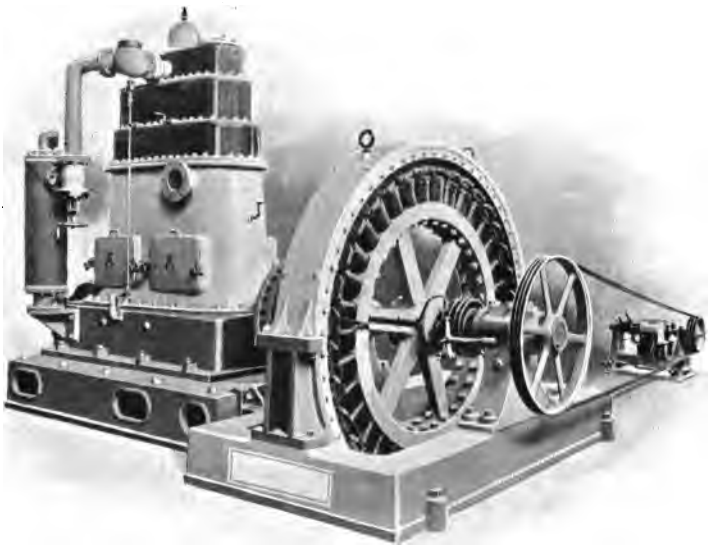


FIG. 106.—Johnson and Phillips Alternator.

resting on insulated contact-rings carried on a cast-iron frame keyed to the shaft. This arrangement may be seen in the front of Fig. 104, and the conductors leading the exciting current thence to the ends of the field-coil circuit will also be noticed.

Fig. 106 is an illustration of a single-phase machine of

the same type, but slightly different construction. This is coupled to a medium-speed engine, the exciter being driven by means of a rope pulley on the end of the alternator shaft. The two conductors connecting the field-coils with the contact- or slip-rings may be seen on one of the spokes of the wheel, the field-bobbins being joined-up in series.

When the ends of the armature-winding are exposed, it is possible to tell at a glance, as in Figs. 104 and 106, whether an alternator is single-phase or polyphase.

One of the early forms of Johnson and Phillips machine (designed by Kapp) had a ring armature. In this the coils were wound round the flattened periphery of a fly-wheel which rotated between double sets of poles something like those in Fig. 89, but wider apart. This type of alternator armature is practically obsolete now.

74. THE PARSONS TURBO-ALTERNATOR.—Messrs. C. A. Parsons & Co., of Newcastle, are the manufacturers of a peculiar type of high-speed engine known as the *steam turbine.* As its name indicates, the principle is the same as that of the turbine water-wheel. There are, in reality, a number of turbines fixed to the same shaft, the steam passing through them one after the other, and causing the shaft to revolve at a very high rate of speed. These steam turbines are connected direct, by means of a flexible coupling, to either a direct-current dynamo or an alternator; the first combination being generally known as a *turbo-dynamo,* and the latter as a *turbo-alternator.* The term *turbo-generator* refers to either class. It is with the turbo-alternator that we are here concerned.

These are made in various sizes, having outputs of from 50 to 2000 kw.; and are wound for either single-, two-, or

Fig. 107.—1500 K.W. Three-phase Turbo-Alternator.

three-phase currents. The smaller sizes have a 2-pole field, and the larger a 4-pole field; the exciting current being furnished either by a small 2-pole dynamo mounted at one end of the shaft, as in Figs. 108 and 109, or from a separate source.

Fig. 107 illustrates a 3-phase turbo-alternator of 1500 kw. capacity at 6000 volts; and some idea of its size may be gathered from the following data:—length, 35 feet; width, 9 feet; height, 8 feet 6 inches; weight, 64 tons. Fig. 108 is a 300 kw. single-phase machine, and Fig. 109 an older form of about the same output.

A section through a 350 kw. alternator F.M. and armature is given in Fig. 110, the same arrangement being common to all except the smaller sizes, which, as already mentioned, have a 2-pole field. Here it will be noticed that the field-coils do not closely embrace the cores; this being so in order to promote ventilation, and thus keep down the heating of both coils and cores, the latter being due to the generation of eddy currents therein. The F.M. cores are of laminated wrought-iron, and each has its respective portion of framework or yoke-piece cast on to it. The coil frames are bolted to the framework by means of the bolts, *B, B*, etc. The armature-core consists of a number of soft iron disks threaded on and securely fixed to the shaft. Round the circumference a number of holes are punched, through some of which are threaded the armature conductors; other and larger holes nearer the shaft serving for the ventilation of the core. In this particular size the armature-core is 18 inches in diameter, and has 60 holes round its periphery, 40 of which carry the conductors.

FIG. 108.—Brush-Parsons Turbo-Alternator.

[This is a new machine, built (under licence) by the Brush Electrical Engineering Co. It is for single-phase work and has a capacity of 300 kw. at a pressure of 2000 volts, and a frequency of 50 ~.]

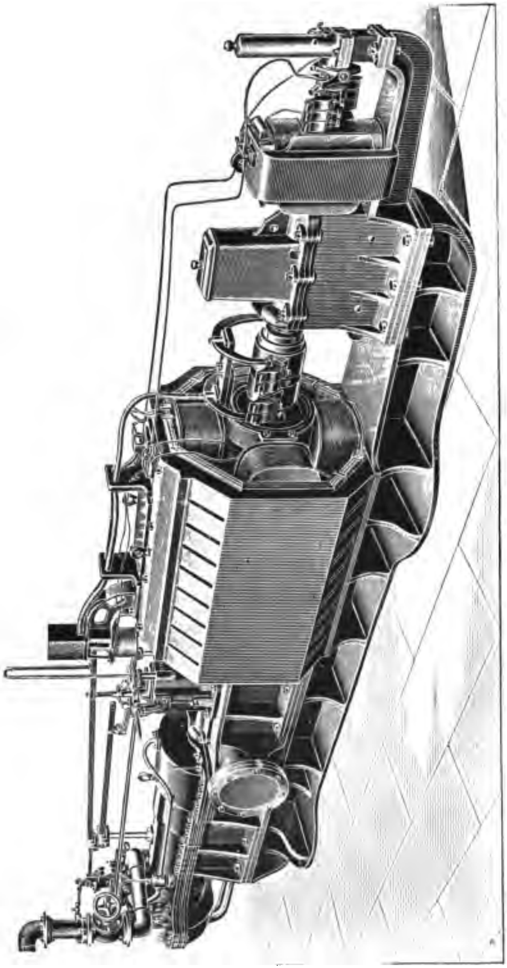


FIG. 109.—Single-phase Turbo-Alternator.

The armature is thus virtually of the drum type, and in spite of its having only two coils, the great speed (generally 3000 revolutions per minute) is sufficient to generate an E.M.F. of 1000 volts in this individual case. Calling one coil *a* and the other *b*, *a a′* are what may be termed the top and bottom turns of one coil, and *b b′* the turns of the other coil, each having ten turns. The two coils are joined in series, and their free ends connected with two collector-rings, each of which has four brushes pressing on it, two at one side and two at the other. From an inspection of Fig. 110 it must be evident that the E.M.F. rises, falls, and reverses simultaneously in both coils, and is always in the same relative direction in both at any given moment. As the coils rotate in a 4-pole field, the E.M.F. changes in direction four times in every revolution, or makes two complete reversals per revolution. The frequency is thus twice the number of revolutions, and in the present case is 2×3000 or 6000 per minute, *i.e.* 100 ∼ per second. The very small 2-pole machines run up to 10,000 revolutions per minute, according to the pressure and frequency required.

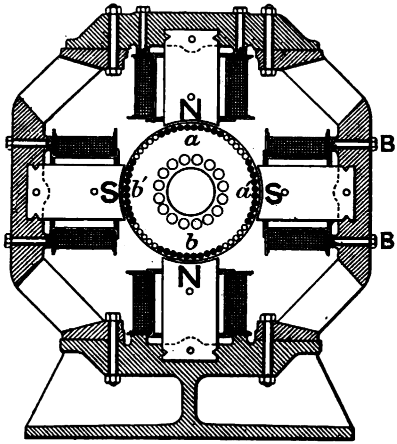


FIG. 110.—Turbo-Alternator (Section).

The steam from the boilers enters the engine through the hand-valve seen at the left of Fig. 109; and a second valve, working automatically, admits the steam to the turbines in a series of gusts, this valve opening once every fifteen revolutions. The duration of each gust is controlled either by a centrifugal governor driven from worm and wheel gearing, or by an electro-magnetic regulator fixed to a bracket on the top of the alternator framework. This regulator has two coils, shunt and series, which tend to suck an armature either up or down, the latter being fixed at the end of a long lever connected with the above-mentioned valve. This lever, according to its position, lengthens or shortens the duration of each gust of steam admitted to the turbines. The shunt or bottom coil of the regulator is connected as a shunt to the F.M. winding, or, what is virtually the same thing, to the terminals of the exciter: and as the pressure of the latter varies as the speed of the machine as a whole, the current passing through the shunt regulator-coil will likewise vary. If the pressure rises, the shunt-coil pulls on the core and tends to decrease the speed. The series regulator-coil carries the main alternating current, and has a laminated core to prevent heating. The pull of this coil increasing with the load, admits more steam to the turbine, and so increases the speed and maintains the pressure. At full load the gusts of steam become blended into an almost continuous blast, the valve closing only momentarily, or not at all. For modern alternating current supply, where alternators are required to run in parallel, the centrifugal governor is always fitted.

At first sight a machine running at such a high rate of

speed would seem to be at a disadvantage with ordinary types revolving at much lower speeds, on account of the friction at the bearings, and the apparent liability of the whole to shake itself to pieces. The former difficulty is overcome by very efficient lubrication. An oil pump is worked by a worm gear, and supplies oil from a central reservoir to all bearings under a pressure of several pounds per square inch, the oil returning by gravity to the same source with practically no waste. Owing to the absence of crank shafts or any to-and-fro (reciprocating) motions in the engine, there is extremely little vibration as compared with ordinary engines, so little indeed that the machine does not need any special foundations, but may stand on any ordinary floor with a packing of wood or lead underneath, and without any holding-down bolts. The construction also of both alternator and exciter armatures is well adapted to a high rate of speed. In addition to this the weight, space occupied, and steam consumed for a given output are said to be much less than with ordinary types of engines and alternators.

75. THE MATHER AND PLATT ALTERNATOR.—Fig. 111 shows the newest form of this make of generator, this having been specially designed for 3-phase work.

The construction is similar to that of the Ferranti "iron-type" and Johnson and Phillips machines, in that there is a fixed face-coil armature, and a rotating radial-pole field system. The latter is energized by the four-pole direct-current machine seen at the front end of the shaft; the field-magnets of this being supported on a pedestal attached to the base-plate. The rotor is unusually massive, so as to act as a fly-wheel as well; and

each magnet coil is readily detachable from its respective core.

The standard sizes of these machines are constructed to work at from 300 to 6500 volts, at a frequency of 40 $\sim$: and the magnet has from 10 to 64 poles, according to its size. The outputs vary from 85 to 5000 kw.

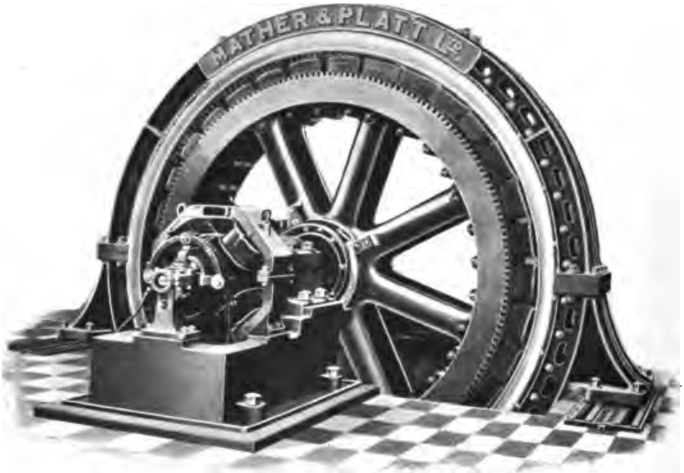


FIG. 111.—Mather and Platt Alternator.

76. OTHER ALTERNATORS.—It is of course impossible to describe every make of alternator, those dealt with having been selected at random as being representative of present-day types. As regards other makers, Crompton & Co., for instance, build two forms of alternator, one with a rotating disk armature, something like that of the Ferranti machine (Fig. 87), and another with a rotating magnet similar to that of the Johnson and Phillips machine (§ 73).

One form of the Siemens alternator has a rotating disk armature, while the Lowrie-Parker machine resembles that in Fig. 111, so far as its field-magnets are concerned.

77. E.M.F. OF ALTERNATORS.—In § 20, the simple formula connecting the E.M.F. (E), speed (n), flux of a pair of poles (F), and the number of conductors (N), in series on an armature was given as:—

$$E = \frac{N \mathsf{F} n}{10^8}$$

This formula is modified to apply to alternators thus:—

$$E \text{ (virtual volts)} = \frac{k\, p\, N\, \mathsf{F}\, n}{10^8}$$

F being the flux through any one pole (or pair of facing poles in the case of a disk armature), p the number of pairs of poles, counting on one side only of the armature in the case of disk machines, and k a figure which depends on the width and shape of pole-faces and armature-coils, and which varies from about 1·1 to 2·8.

The frequency of alternators was dealt with in § 44.

78. SYNCHRONIZING OF ALTERNATORS.—When we think of the number of times the current from an alternator changes in direction in the course of a second, it is difficult to understand how such machines can be made to feed in parallel into bus-bars (§ 238). In early days this apparent difficulty was assumed to be insurmountable, but now it has been entirely overcome, alternators being nearly always connected together in this way.

Suppose there are one or more machines already feeding into the bus-bars, and it is desired to switch-in another.

Before doing this the incoming machine must be *synchronized* with those already working, that is to say, it must be run up to exactly the same frequency, and its alternations got into step with those on the bus-bars. When once synchronized and switched-in with the others, the machines tend to keep one another in step.

One method of synchronizing is as follows. The primaries of two step-down transformers (§ 189) are connected, one to the bus-bars, and the other to the machine to be synchronized: while the secondaries are joined-up in series and connected to an incandescent lamp and a voltmeter, as depicted in Fig. 112. When the currents in the secondaries are in step, they work in unison; but if out of step, they oppose each other. If the frequency (*i.e.* the speed) of the alternator to be switched-in is not correct, the lamp lights up and goes out at rapid intervals. The speed of the machine must then be adjusted until the light of the lamp rises and falls only a few times a minute. The machine is then switched-in at the moment the lamp is at full incandescence, and the voltmeter shows the correct pressure; it being then in synchronism with the others. This arrangement is further illustrated in Fig. 392.

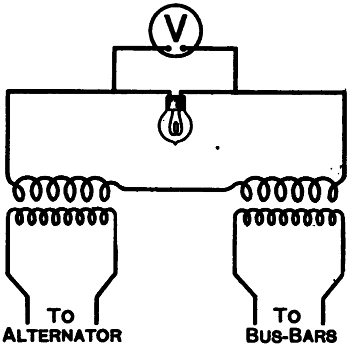


FIG. 112.—Synchronizing Arrangement.

79. Double-Current Generators.—A double-current generator is a machine which furnishes either direct or alternating (single-, two-, or three-phase) current as required, from one and the same armature. Or both direct and alternating currents may be taken from the machine at the same time.

As will have been gathered from Chap. *VIII.*, every

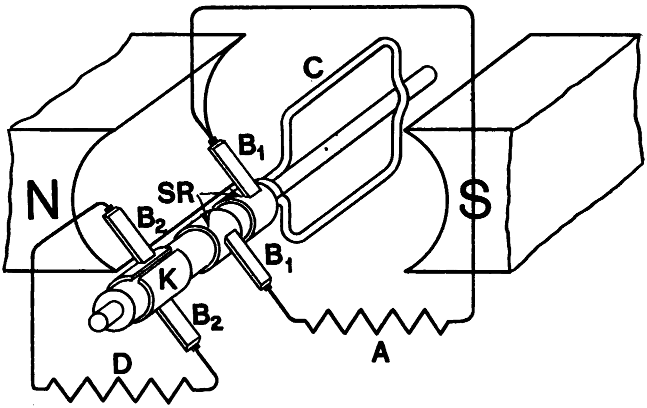


Fig. 113.—Simple Double-Current Generator.

direct-current generator is in reality an alternator, with the addition of a commutator for rendering the current unidirectional in the outer circuit. Thus, if any type of direct-current dynamo have slip-rings or collectors mounted on its shaft, in addition to its commutator, the rings being connected to certain points of the armature winding, both direct and alternating currents may be taken from it.

Fig. 113, which should be compared with the figures of

the simple alternator and simple direct-current dynamo in Chap. *VIII.*, represents a simple double-current generator. When the coil C is rotating in the field $N S$, an alternating current will flow in the circuit A, which is connected to the coil by the brushes $B_1 B_1$ and slip-rings SR. In the circuit D, on the other hand, a direct current will flow, since this is connected to the ends of C by the brushes B_2, B_2, and the two-part commutator K. Thus this simple

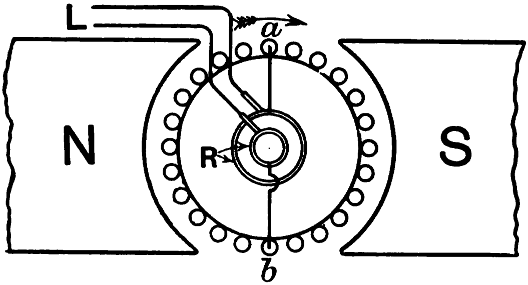


FIG. 113A.—Two-pole Armature connected for Single-phase Work.

device will furnish either a direct or alternating current as desired, or both at the same time.

Fig. 113A illustrates the outline of a drum or ring armature rotating in a 2-pole field, the slip-rings R being respectively connected to any two diametrically opposite points a and b. L are the outer circuit leads connected through brushes to the slip-rings. Now, if, starting from the position shown, the armature rotates in the direction of the curved arrow, during the first half-turn a will be + and b −, neglecting the distortion of the field (Chap. *VIII.*); while during the second half-turn, a will

be − and b +. For, in a 2-pole machine, the E.M.F. in the armature is reversed twice, or makes one complete period in every revolution. The frequency of the current from such a machine would be very low, it being proportional to the revolutions per second. Thus if the machine ran at 420 r.p.m., the frequency would be $420 \div 60 = 7\sim$, which would be altogether too low for practical work, where the frequencies in use vary from $25\sim$ to about $100\sim$. To get even so low a frequency as $25\sim$ would necessitate a 2-pole machine being driven at $25 \times 60 = 1500$ r.p.m.—rather too high a speed for machines of any size.

In a multipolar machine, on the other hand, the frequency at a given speed would be the greater the greater the number of pairs of poles. Thus assuming the speed to be 420 r.p.m., the frequencies of machines with different numbers of poles would be :—

2-POLE.	4-POLE.	6-POLE.	8-POLE.	10-POLE.	12-POLE
$7\sim$	$14\sim$	$21\sim$	$28\sim$	$35\sim$	$42\sim$

and so on. The frequency is calculated in the same way as with alternators (§ 44). Thus it is that double-current generators are multipolar in form; but except for the presence of the slip-rings, they are hardly to be distinguished from ordinary multipolar direct-current machines, some makes of which are illustrated in Chap. *IX*.

If f be the frequency, n the speed in r.p.m., and p the number of field-poles, the formula connecting the quantities is :—

$$f = \frac{n \times p}{60 \times 2}$$

We divide by 60 to bring n to revolutions per second, and by 2 to bring p to pairs of poles.

Example.—A machine is to develop a frequency of 40∼ at a speed of 800 r.p.m. How many poles must it have?

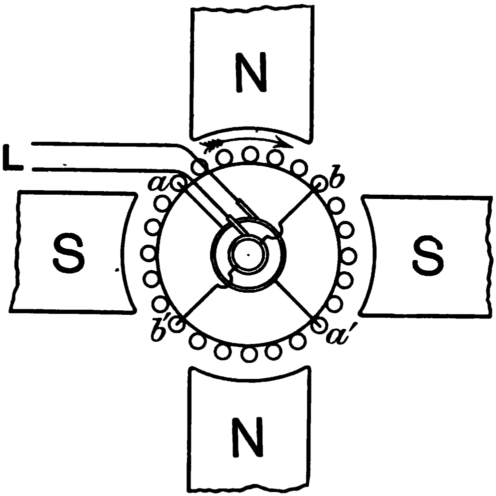


Fig. 114.—Four-pole Armature connected for Single-phase Work.

Here :—
$$40 = \frac{800 \times p}{60 \times 2}$$
$$i.e. \quad p = \frac{60 \times 2 \times 40}{800}$$
$$= 6 \text{ poles.}$$

Fig. 114 gives the outline of a drum or ring armature in a 4-pole field, and it will be clear that any conductor a, in making one revolution, will cut through four fields;

and the E.M.F. therein will consequently undergo four alternations or two complete periods or cycles per revolution (§ 43). That is to say, the frequency at a given speed will, as already explained, be twice as great as with a 2-pole field. To connect up such an armature for single-phase currents, two diametrically opposite points

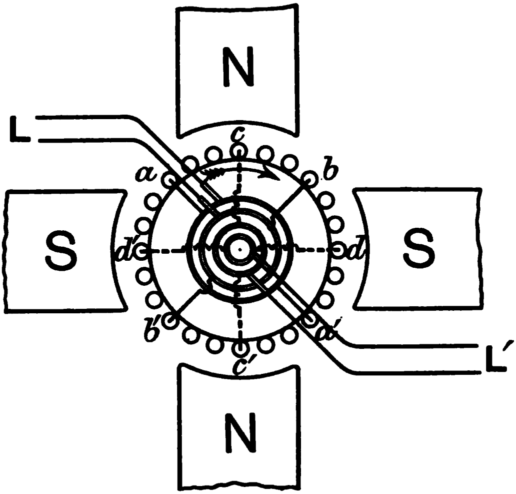


FIG. 114A.—Four-pole Armature connected for Two-phase Work.

a a′ would be joined up to one collector ring; and two other points *b b′*, on a diameter at right angles with *a a′*, to the other ring. The outer circuit leads *L* are connected to the slip-rings through brushes as before. In a 6-pole, 8-pole, 10-pole, or 12-pole machine there would be respectively 3, 4, 5, or 6 equidistant connections to each slip-ring.

For 2-phase work there would be four slip-rings, the connections of a 4-pole 2-phase armature being given in Fig. 114A. Here $a\,a'$ and $b\,b'$ are the connecting points of one phase (as in Fig. 114), and $c\,c'$ and $d\,d'$ those of the other phase, the latter being 45° in advance of the former,

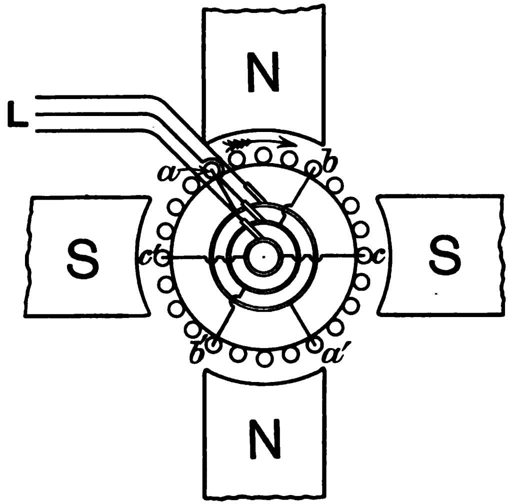


FIG. 115.—Four-pole Armature connected for Three-phase Work.

and the connections indicated by dotted lines. L are the leads to one outside circuit, and L' those to the other.

Fig. 115 shows the connections of a 4-pole armature for 3-phase work, there being generally only three slip-rings in this case. Here $a\,a'$, $b\,b'$, and $c\,c'$ (60° apart) are the respective tappings for the three phases, and L are the leads from the outer circuit.

As will be evident from what has been said above about the speed and frequency, large double-current generators have a greater number of poles than four; but this number has been shown in the figures in order that the connections shall not be too complicated. In Figs. 113A to 115 the commutator connections are not shown, but these are the same as in an ordinary dynamo. The excitation also is similar to that of a direct-current machine.

If a double-current generator, when used for direct-current work only, had a maximum output of say 1000 kw., such also would be its maximum output when employed as an alternator alone. And when used to furnish both kinds of current simultaneously, the sum of the loads on both circuits would have to be kept within the figure indicated.

The uses of double-current generators are briefly referred to in § 217, while two actual machines are illustrated in the next paragraph.

79A. TYPES OF DOUBLE-CURRENT GENERATOR.—One form of double-current generator (British Westinghouse) is shown in Fig. 116. This is a 6-pole machine, and is provided with four collector-rings for 2-phase current, as will be seen to the left of the figure. On the right is the direct-current commutator, from which the current is taken off by means of carbon brushes. The bearings are of the self-oiling type, and are provided with oil-level indicators. The machine is fitted with a pulley for belt-driving, and is mounted on a slide bed. Its total or combined output is 200 kw. This construction is identical with that of a direct-current generator for the same output, with the addition of the slip-rings and their connections to

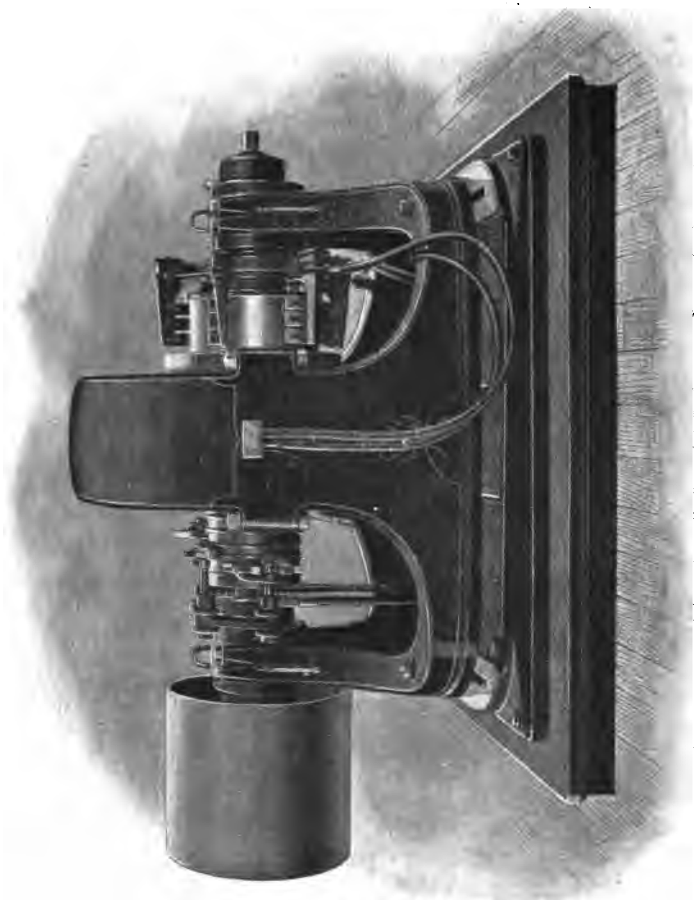


FIG. 116.—Double-Current Generator (British Westinghouse Co.).

the armature-windings, and the necessary lengthening of the frame and shaft.

Fig. 117 illustrates another form of double-current

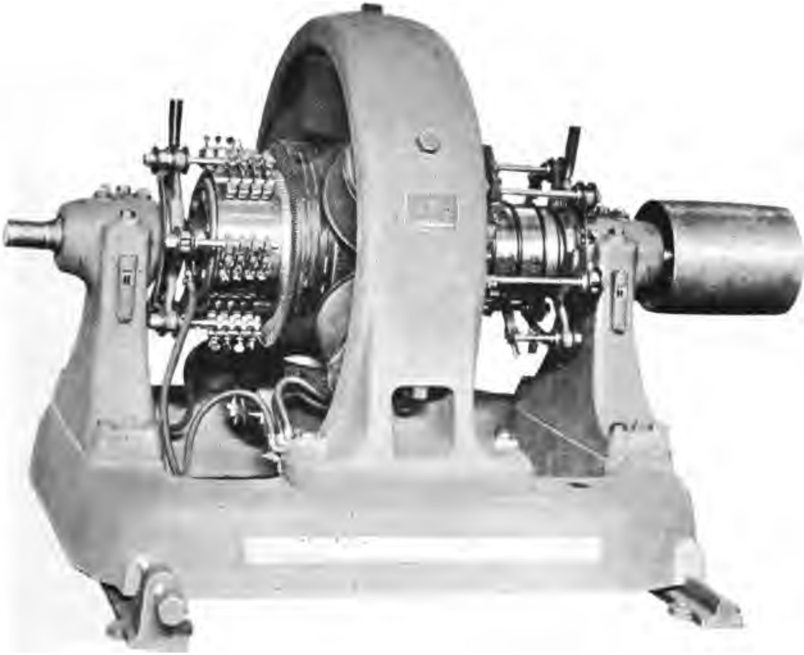


FIG. 117.—Double-Current Generator (British Thomson-Houston Co.).

generator. This is a 6-pole machine, having an output of 50 kw. at 240 volts, and running at 1200 r.p.m., its height being about 4 feet 6 inches. The figure shows very clearly the direct-current commutator on the left, and the 3-phase collector-rings on the right.

As mentioned later on in § 205, machines of this type may be used as current-character transformers. Thus a polyphase current from an independent source, led through the slip-rings, will drive the machine and cause direct current to be given out at the commutator. Similarly the machine might be driven by direct current, and polyphase current drawn from it. The former (*i.e.* the transformation of polyphase to direct current) is its chief use as a rotary converter.

CHAPTER XII.—QUESTIONS.

In answering these questions, give sketches wherever possible.

1. Why are alternators so commonly separately excited? How can they be made to be self-exciting? [Ord. 1896.]

*2. Describe briefly in how many ways alternators may be classified.

*3. Define the terms rotor and stator as applied to alternators. Does the rotor always carry coils?

*4. Distinguish between single-, two-, and three-phase machines. Give a simple diagram of your own showing how the armature-coils are connected up to each other, and to the outer circuits, in each of the three cases.

5. What is the difference between radial-coil and face-coil armatures?

6. Why are the collectors or slip-rings of an alternator sometimes placed at opposite sides of the rotor?

7. Some alternator armatures have iron cores to the coils, and some have non-magnetic cores. Why is there this difference?

8. How may the connections of an armature be altered to give different E.M.Fs., without altering the speed?

9. Sketch some form of multipolar field-magnet which is excited by a single coil. [Ord. 1898.]

10. Describe the construction of any form of alternate-current dynamo. [Ord. 1891.]

*11. Give two or three simple sketches, showing essential features of an alternator or polyphase generator, having no moving coils. [Prel. 1902.]

12. Make a diagrammatic representation of a three-phase generator, and state how many poles would be required if the rotor turned at 120 revolutions per minute, and the frequency of each current was to be 60. Calculate the product $n \times N$ if the voltage is to be 10,000, where n stands for the number of turns in each of the three rotor windings, and N is the mean effective flux in C.G.S. lines emanating from one field-pole. [Ord. 1901.]

13. You have to design an alternator to give 100 kw. at 500 volts. State how you would proceed to determine the principal dimensions of the armature. Give an example and obtain a first approximation of the dimensions. [Ord. 1902.]

14. Describe, with sketches, a form of synchronizer for use in throwing alternators into parallel, and explain the process of using it. [Ord. 1899.]

15. Explain clearly why two-phase and three-phase alternators give greater output for their size than single-phase machines. Has the three-phase generator any advantage over two-phase in this respect? [Ord. 1903.]

16. What is a double-current generator, and what are its uses, and its advantages over ordinary generators?

17. Draw a diagram of an 8-pole direct-current armature, with the connections to slip-rings for 3-phase current generation. What would be the frequency of the current if the armature were rotated at 550 r.p.m.?

inductance. If used on motor or arc-lighting circuits its reading would be proportional to the apparent watts, which would then be greater than the true watts. A true energy meter, on the other hand, takes account of phase-difference (§ 60).

*81. CLASSIFICATION OF METERS.—Electricity meters may be further divided into three classes with regard to their principle of construction and action, viz. :—

(*a*) Chemical or electrolytic meters.

(*b*) Motor meters.

(*c*) Clock meters.

Class *a* depend for their action upon the chemical effect of the current, and obviously can only be used on direct-current circuits. With these, the amount of electro-chemical action is proportional to the quantity of electricity that has passed through.

In motor meters, the counting mechanism is actuated by a motor through which the whole or a definite fraction of the current passes.

Clock meters are of two kinds. In one, the rate of going of a clock is affected by the current, the difference between this and an unaffected clock being registered by the counting mechanism. In the other kind, a clock drives a counting mechanism through intermediate gear controlled by the current. When the current is off, the counting mechanism is unaffected by the clock; when the current is on, the rate of counting or of registering is proportional thereto. The best types of clock meter have self-winding or electrically-propelled clocks.

Meters may further be classified according as they are ordinary or *prepayment meters.* In the latter, the supply

is given on the insertion of a coin, the pressure being automatically shut off, or else reduced so that the lamps burn dimly, when the coin's worth has been delivered: and automatically resumed or restored to the normal when a fresh coin is inserted. Such are also known as *coin-freed* or *money-in-the-slot* meters.

82. LIST OF METERS DESCRIBED.—Twelve meters and three demand indicators are described and illustrated in the following paragraphs, these being as follows:—

	METERS.	CURRENT.
Electrolytic.	(1) Bastian (§ 83).	Direct.
	(2) Schattner prepayment (§ 84).	Direct.
	(3) Wright (§ 85).	Direct.
Motor.	(4) Shallenberger (§ 86).	Alternating.
	(5) Westinghouse (§ 87).	Alternating.
	(6) Elihu Thomson (§ 88).	Direct or Alternating.
	(7) Ferranti (§ 89).	Direct.
	(8) Hookham (§ 90).	Direct.
	(9) „ (§ 91).	Direct (for small currents).
	(10) „ (§ 92).	Alternating.
Clock.	(11) Aron (§ 93).	Direct or Alternating.
	(12) Johnson and Phillips (§ 94).	Direct or Alternating.

DEMAND INDICATORS.

(1) Wright (§ 97).
(2) „ three-wire (§ 98).
(3) Atkinson-Schattner (§ 99).

*83. THE BASTIAN ELECTROLYTIC METER.—This meter, which is, of course, usable with direct currents only, is as simple as it is possible for a meter to be. It consists of a tall glass vessel nearly filled with acidulated water, at the bottom of which, in a special ebonite holder, two platinum plates are placed; the whole supply of current being led

down to one plate and back from the other through conductors fitted in ebonite tubes. The proportion of acid to water is about 1 to 20, and the amount of liquid electrolyzed will depend upon the varying current that passes, and the time that it flows; the level of the liquid gradually descending. In other words, each little increment of current × time will register itself by a corresponding quantity of liquid electrolyzed; the total quantity at the end of any given period being proportional to the ampere-hours of flow. Each instrument has a graduated scale fitted to the front of its glass containing-vessel, and is calibrated for a given voltage. Hence the scale may be and is marked off direct in Board of Trade units, the volume

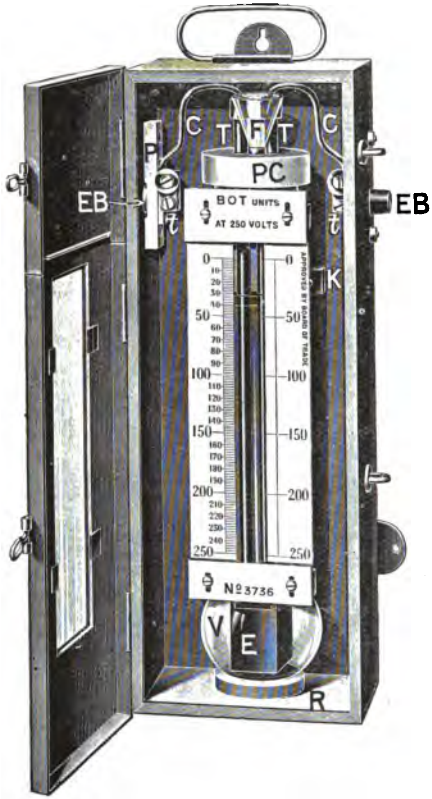


FIG. 118.—Bastian Meter.

of water decomposed being proportional to the quantity of electricity used.

A very clear illustration of the complete instrument is given in Fig. 118. *T, T* are the ebonite tubes down which the lead conductors *C, C* pass to the platinum plates; the latter being shielded in an ebonite box *E* partly open at top and bottom, and kept apart by a slip of ebonite. *P C* is a porcelain cover which fits on the top of the containing-vessel *V*, and through holes in this the tubes *T, T* pass.

One of the leads running from the supply-terminals to the distribution-board is cut, and the two ends passed through ebonite bushes *E B, E B* to terminals *t, t*, the latter being each mounted on a porcelain block screwed, as at *P*, to the side of the enamelled sheet-iron case containing the whole. The glass containing-vessel has a rounded bottom which rests on a rubber ring *R*, while at the top it is held in, but is easily detachable from, a clamp fixed to the back of the case at *K*.

The scale is of zinc, and on starting, the liquid is poured in through the glass funnel *F* until its level corresponds with the zero mark on the scale, paraffin oil to the depth of about three-eighths of an inch being run in on the top of the electrolyte to prevent evaporation. The line of demarcation between the oil and the electrolyte is clearly discernible, and is shown in the figure by a thin white line standing at the 40 B. o. T. units level. The outer case is provided with an upper and lower hinged front, the latter being fitted with a window through which the scale can be viewed.

For 3-wire circuits, two ordinary meters are fitted up

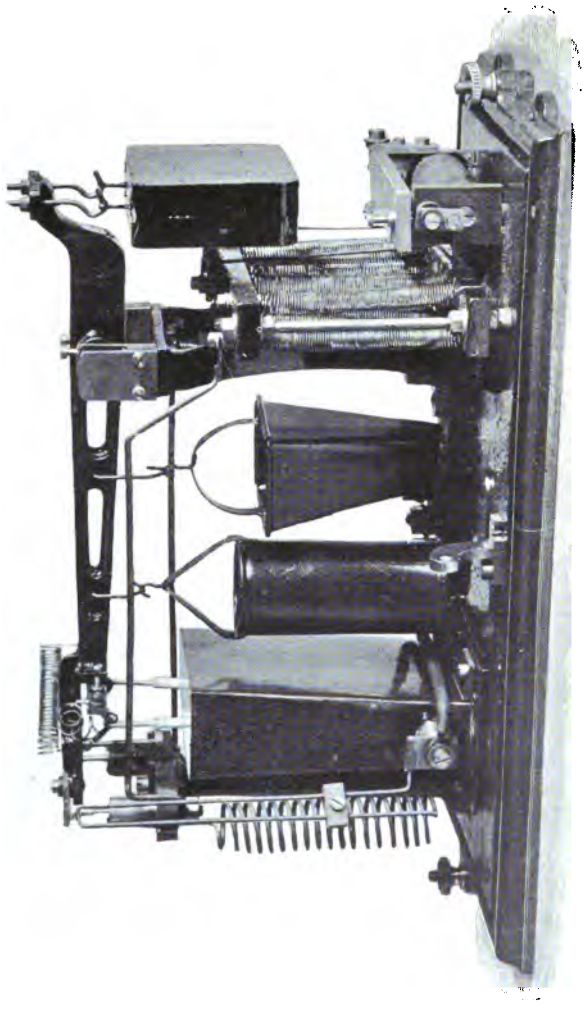


FIG. 119.—Schattner Prepayment Meter.

in one case, these being connected one in each of the two outer leads.

*84. THE SCHATTNER ELECTROLYTIC PREPAYMENT METER.—The spread of electric lighting among the poorer classes of consumer has led to the necessity of what are known as prepayment meters. A very interesting apparatus of this type, acting on the electrolytic principle, and therefore available for direct currents only, is that known as the Schattner meter.

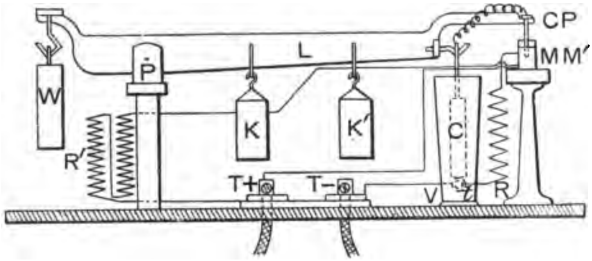


FIG. 120.—Diagram of Schattner Meter.

A general view of this is given in Fig. 119, which should carefully be compared with the diagram in Fig. 120; these two figures, it will be noticed, illustrating the apparatus reverse ways. Referring to the latter, *L* is a lever pivoted at *P*. At the right-hand end of this is hung a thick copper plate or block *C*, and at the opposite end a balance-weight *W*. *K* is a cup which catches and holds the coins as they pass through the slot, while in a second cup *K′* the meter inspector places balance-weights equivalent to the cash he takes away. *C* is immersed in a solution of copper sulphate contained in the copper vessel *V*, which acts as

the kathode, and is connected through *t* with the main terminal *T*—. *M* and *M'* are mercury cups into which the contact-pins *C P* dip, the latter being carried at the extremity of the lever *L*. *R* is a low resistance carrying the main current, and across this the depositing-cell *V* is connected as a shunt. *R'* is another and larger resistance connected between the two mercury cups. The current passes into the meter at *T* + and leaves at *T*—. The depositing-cell, mercury cups, and resistances are shown in combined perspective and diagram in Fig. 121. Contact is only broken in the right-hand cup *M'*, which is shallower and contains less mercury, creosote oil being poured in on the top of the mercury in both to prevent splashing and oxidation, and to lessen sparking. The bridge-piece which carries the contact-pins *C P* is connected with the anode *C* by a short length of wire *w*. A thin layer of machine oil is poured on the top of the copper sulphate solution to prevent its "creeping."

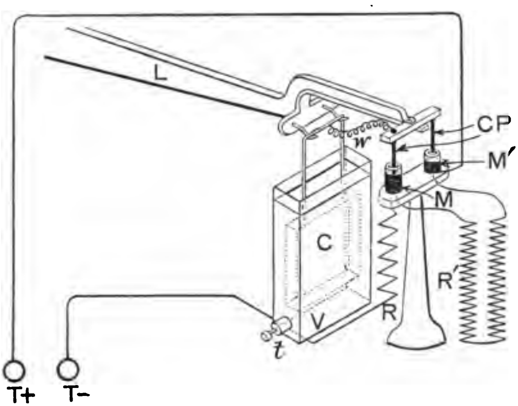


FIG. 121.—Depositing Cell of Schattner Meter.

As already stated, the main current passes through the low

resistance R, only a definite fraction of it depositing copper in V. When a coin is passed through the slot into K, the lever is weighted down so that contact is made through the mercury cups, and the consumer can obtain current through his switches and lamps. Exactly in proportion to the quantity of electricity used, copper is deposited from C on to V; and by the time the loss of weight in C counterbalances the increase due to the coins in K, contact will be broken at $C\,P$, and the main supply stopped. The lights will not be extinguished, however, as that would result in great inconvenience to the consumer. They are merely dimmed, owing to the current now having to pass through R', which reduces the pressure; and thence through R and the cell. This dimming of the light thus indicates when it is necessary to put more money in the slot; and the light is reduced to such an extent that the consumer is impelled to insert more coins. It should be noted, by the way, that whether the current flows through $C\,P$, or simply through R', it is registered by the cell.

This resistance across the mercury cups is not a fixed one, as might be thought from Figs. 120 and 121; as, with only one or two lamps in circuit, the dimness produced would not be sufficient; or if it were, the consumer could remedy the defect by putting in lower voltage lamps. Or if R' were sufficient to dim a few lamps, it would practically extinguish the light if a large number of lamps were in circuit. This resistance therefore is arranged in two sections, and is connected up with a relay in such a way that the light will be properly dimmed whatever be the number of lamps in circuit. This relay can be seen to the right of Fig. 119, and its connection is shown in Fig. 122.

Here R' is a medium resistance and R'' a high resistance; and in series with these is a relay coil R C. M and M' are the mercury cups. When only a few lamps are alight, the current in R C is insufficient to operate the relay, and the whole of the resistance $R' + R''$ is kept in circuit. If there are many lamps alight, the current energizes the relay sufficiently to draw down the armature A, thus short-circuiting R'' at the contact C'. The relay only acts when the main circuit is broken at the mercury cup, and then only when there are a comparatively large number of lamps "on." In the smallest meters of this type, a glow-lamp is used in place of the resistance wire R', and R'' dispensed with.

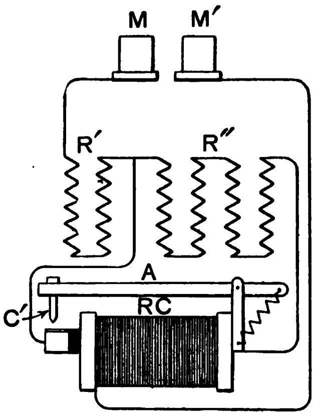


FIG. 122.—Relay of Schattner Meter.

The Schattner meter is also arranged as an ordinary meter without the prepayment arrangement.

*85. THE WRIGHT ELECTROLYTIC METER.—This instrument is the newest of all described in this chapter, and is certainly one of the most interesting. It may be briefly described as an electrolytic cell shunted by a platinoid resistance of such value that only about $\frac{1}{200}$th part of the main current passes through the cell. The electrolyte is a solution of mercurous nitrate, a colourless liquid which at first sight might be mistaken for water. The anode is mercury, and the kathode platinum. The

kathode is made in the form of a funnel, and the mercury which is liberated at its surface does not adhere thereto, but, after collecting and forming into minute globules, runs through into a graduated collecting tube. The amount thus collected is obviously a measure of the quantity of electricity that has passed through the cell; and if, as is usually the case, the instrument is calibrated for a given pressure, the scale may be marked off direct in B. o. T. units. The tube which collects the mercury from the kathode is in the form of a syphon; and when full, automatically empties itself into a larger tube surrounding and extending below it, which latter is also graduated. The syphon tube generally reads up to 100 units, and the outer tube up to 1000, though the exact range depends upon the pressure; and the meter reading is the sum of the readings in both tubes. Two most interesting points about this meter are that the electrolyte and mercury are contained in an hermetically sealed vessel; and that by tilting the vessel, the mercury is emptied into a reservoir bulb, and the tubes left free for a fresh series of indications. The hermetic sealing-up of the electrolyte and mercury is only possible because no gas is given off; while the ease with which the meter can be "reset," and that without handling the electrolyte, etc., is a most advantageous feature.

The principle of the instrument may be explained with the help of Fig. 123, which shows the actual form of the glass cell; the connections being given diagrammatically. *M* is the mercury reservoir from which the mercury runs into an annular trough *A*. A side view of this arrangement is given at II, and a section at III. Between the +

and – terminals is connected the platinoid resistance *PR*,

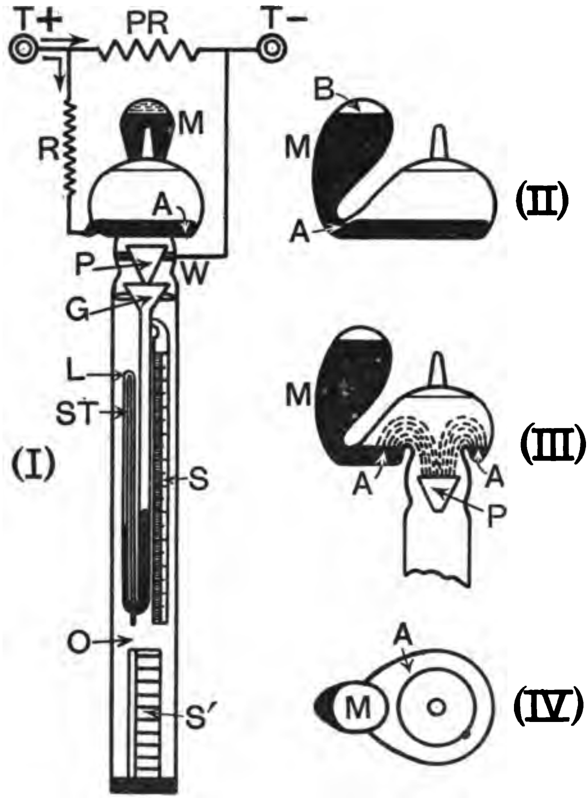


FIG. 123.—Wright's Electrolytic Meter.

the shunt current being taken through a fine wire resistance *R*, and led by a platinum leading-in wire to the trough

A and the mercury therein. From this mercury the current curves over the edge of the trough through the

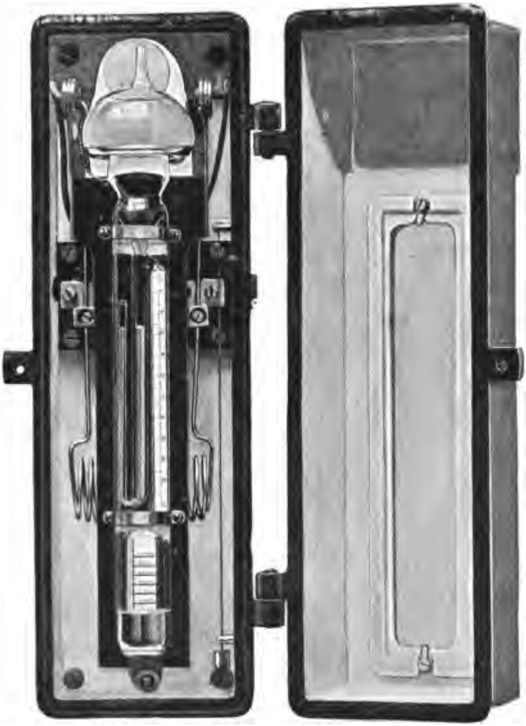


FIG. 124.—Wright's Electrolytic Meter.

electrolyte to the inner surface of the platinum funnel *P*, as shown at III, and from there it passes by a platinum leading-out wire *W*, to the negative terminal.

The electrolysis of the solution of mercurous nitrate

FIG. 125.—Wright Meter and Demand Indicator fitted together.

which, it should be noted, fills the *whole* of the glass vessel with the exception of an air bubble at *B*, results, as already mentioned, in the deposition of mercury on the surface of the funnel *P*. But as fast as the metal is deposited from the solution upon the kathode, the solution dissolves mercury at the anode so as to keep its strength constant.

The mercury which collects on the kathode drops by imperceptible degrees into the glass funnel *G*, and syphon tube *S T*; and the units

corresponding with a given height may be read off from the scale S. As soon as the mercury in both legs of $S\ T$ rises to the level L, the syphon action comes into play, and the whole is precipitated to the bottom of the outer tube O, which, as already explained, is provided with a second scale S'. When the meter requires resetting, which is only necessary at intervals of some months, the outer tube O is tilted up, whereupon the mercury in this and in the syphon tube runs back into the reservoir M.

The general appearance of the apparatus, with the front of the cast-iron case opened, may be gathered from Fig. 124, the height being about 14 inches. The glass cell is mounted on a board hinged at the top to allow of the resetting of the meter, and behind this board may be seen a portion of the platinoid coil which carries the main current.

Fig. 125 shows one of these meters, and a Wright Demand Indicator (§ 97) fitted together in the same case, the whole forming a very handy combination.

This meter is easily arranged for use on a three-wire circuit in much the same manner as the demand indicator (§ 98). Referring to Fig. 168 and the explanation of same, we may fit it to the Wright meter by regarding H as the electrolytic cell with its fine-wire resistance in series, and $A\ B$, $A\ C$ as a split main current resistance taking the place of $P\ R$ in Fig. 123.

*86. THE SHALLENBERGER METER.—This instrument belongs to the class of motor meters, and will only work with alternating currents. Fig. 126 shows the meter with its covers removed and placed on one side. The motor armature or moving part is depicted in Fig. 127, and con-

sists simply of an aluminium disk *D*, and the aluminium vanes *V*. The lower end of the spindle, the vanes, and the edge of the disk can also be seen in Fig. 126.

The alternating current to be measured is passed through the oval-shaped coil seen between the vanes and the

FIG. 126.—Shallenberger Meter.

registering-dials (Fig. 126). Inside this large coil is a smaller one which is short-circuited on itself, and within this smaller or secondary coil is the aluminium disk. It will be noticed that the magnetic axis of the secondary coil is placed at an angle of about 45° with that of the main or primary coil, and it is because of this that the disk is made to rotate.

When current passes through the main coil, a secondary current, which lags slightly behind the main current, is induced in the inner coil. In consequence of this and the fact that the magnetic axes of the two coils are at an angle, what is termed a rotary magnetic field is set up, and this induces eddy currents in the disk and causes it to rotate, the rotation being rendered slow and steady by the vanes. Were it not for the vanes, the disk would turn at a rate varying as the square of the current; but as the retardation due to the vanes varies as the square of the speed, it follows that the rotation of the disk is directly proportional to the strength of the current.

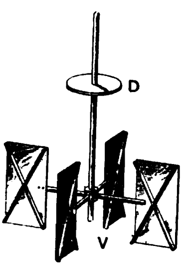


FIG. 127.—Moving part of Shallenberger Meter.

Although both the construction and action of the instrument are beautifully simple, the latter is not easy to explain in every-day language. In Fig. 128, *M* is the main coil, *S* the secondary coil, and *D* the disk. Consider one cycle of the current in *M* and of the induced current in *S*, and the magnetic fields set up thereby.

Suppose, to start with, the field due to *M* is in the direction of the arrow 1, then the arrow 2 gives the field due to the first induced current in *S*, which follows directly after that in *M*. Immediately after this, the reverse current in *M* will give a field in the direction of the arrow 3; and lastly the field of the reverse secondary current will be as arrow 4. The result is a field rotating in a clockwise direction, as shown by the curved arrows, and this will drag the disk round the same way.

The instrument records in ampere-hours, and may thus

be connected to circuits at any voltage; the multiplication of the reading on the dials by the circuit pressure giving watt-hours. Generally, however, each instrument is calibrated at a certain voltage, and the dials arranged to read direct in Board of Trade units. The angle between the coils is adjustable, the angle varying with the frequency.

87. THE WESTINGHOUSE METER.—This apparatus, which also will only act with alternating currents, resembles the Shallenberger meter in that its moving part consists simply of an aluminium disk which is set in motion by a rotary magnetic field. The difference between the two meters, however, lies in the way in which the rotary field is set up.

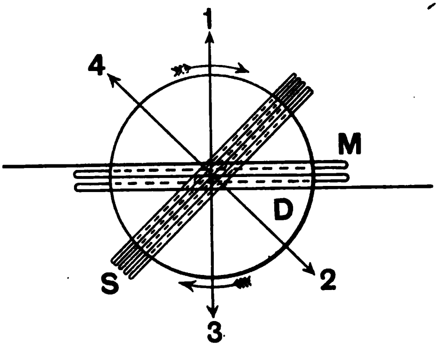


FIG. 128.—Illustrating the Action of the Shallenberger Meter.

The parts of this meter are illustrated by the diagram in Fig. 129. Here *D* is the aluminium disk mounted on a vertical spindle, the upper end of which carries a worm gearing into the usual train of counting-wheels. *I, I, I* is a laminated iron core carrying two upper pole-pieces at *P*, *P*′, which are separated by a vertical gap *V*; and a lower pole-piece at *P*″. As will be explained later, a rotating field is set up between the upper and lower poles, this acting

on and rotating the disk *D*, which is pivoted in the field.

S, *S* are the two portions of the shunt-winding, which are so connected as to magnetize the core *I*, *I*, *I*, as a continuous ring, the field traversing the vertical air-gap *V* between *P* and *P'*. Around the pole-piece *P''* is wound the series coil *SE* carrying the main current, and the field of this traverses the horizontal air-gap between the upper and lower poles.

In series with the shunt coil is connected an inductive resistance, which consists of a fine wire coil wound on an iron core fixed in the base of the meter. This is indicated at *IR* in the figure.

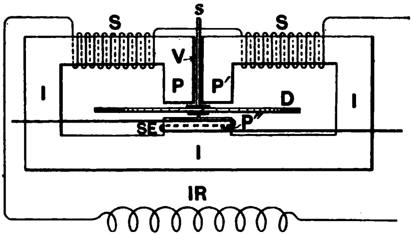


FIG. 129.—Diagram of Westinghouse Meter.

The necessary braking action is afforded by a permanent magnet whose poles are brought close together on opposite faces of the disk. As the disk is rotated by the rotary magnetic field, other eddy currents are generated in it by its motion through the permanent magnetic field; and a consequent "drag" is exerted, which has the effect of curtailing the speed of rotation of the disk. This magnet is not indicated in Fig. 129, but may be seen at *M* in Fig. 130.

Fig. 130 shows the meter with its cover removed. Here *S*, *S* are the shunt coils, *IR* the inductive resistance, *D* the disk, and *M* its controlling-magnet. The terminals

are fitted in a box *B* at the top of the instrument; and right in front are the counting-dials. In Fig. 131 the counting-dials, disk, and controlling-magnet have been removed to enable the other parts to be more clearly shown. Here the shunt and series coils, as well as the inductive resistance, will be noticed, and the actual iron circuit should be compared with that in the diagram given in Fig. 129. Over the shunt coils are wound short-circuited compensating coils, whose function it is to prevent the disk rotating under the influence of the shunt-winding alone; *i.e.* when there is no current in the main circuit.

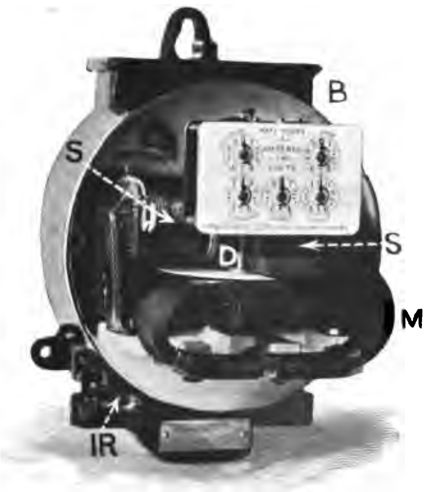


FIG. 130.—Westinghouse Meter.

The action of this meter is not easy to explain in precise language. It will, however, be readily understood that there is considerably more inductance in the shunt than in the series circuit, so much more in fact, that the field due to the former may be assumed to lag about 90° in phase behind that due to the series-winding. Most of the field due to *S, S* traverses the vertical air-gap *V*, but a portion may be assumed to curve round between the poles *P* and *P′* and pass partly through the disk *D*. We have thus

one alternating field, due to SE, passing through the disk; and a second alternating field, due to S, S, skimming the top of the disk. It is the interaction between these and the eddy currents induced by them in the disk that sets the latter in motion. Taking into account the braking action due to the permanent magnet, the rate of rotation of the disk will at any given moment be proportional to the watts being used in the circuit, so that the instrument is a true energy meter, or as the makers prefer to call it—an *integrating wattmeter.*

FIG. 131.—Westinghouse Meter.

***88. THE ELIHU THOMSON METER.**—This is a motor meter, and is named after its inventor, Prof. Elihu Thomson, an American electrician. It is adapted for both direct and alternating currents. Its makers used to term it a recording wattmeter, but this is inaccurate, as the instrument registers energy, not power merely: that is to say, it is a watt-hour or energy meter (§ 80). Moreover, a recording instrument is one which draws a line across a chart,

enabling the value of the quantity recorded, at any given past time, to be ascertained. In fact a *recording wattmeter*, properly so called, is similar in principle to a recording voltmeter or ammeter (Chap. *VII.*). A meter totals up the quantity to the time of observation, without any indication

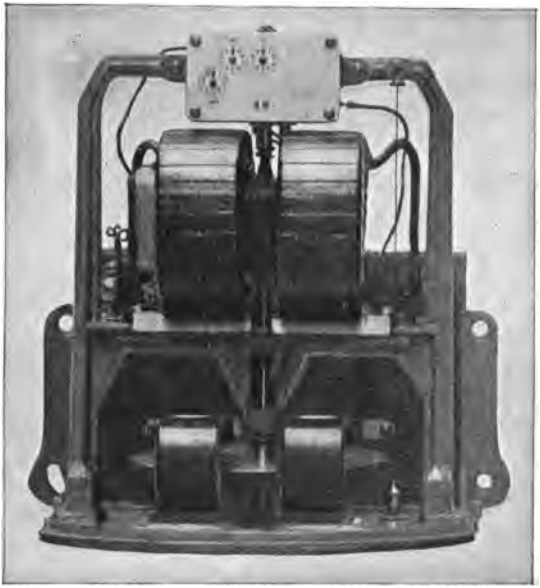


FIG. 132.—Elihu Thomson Meter.

of the variation in the demand. The makers now call this instrument an *integrating wattmeter*, and this name, it will be seen, is correct.

The Elihu Thomson meter, which is shown in Fig. 132 with cover removed, consists of a peculiarly-constructed

electromotor, whose revolutions are counted and registered in the ordinary way by means of an endless screw or worm gearing in a train of wheels. Fixed to the bottom of the vertical motor shaft is a copper or aluminium disk, which revolves between the poles of two permanent horseshoe magnets, the arrangement acting like a miniature magneto-dynamo on short-circuit. This is for the purpose of retarding the revolution of the motor armature, which otherwise would run at an excessive speed. The retardation is caused by the "drag" which is set up between the magnets and the eddy currents induced in the copper disk.

The current to be measured passes through two fixed coils of thick wire, connected in series. The armature, which revolves in the field of these coils, consists of a hollow frame wound drum-wise with a set of coils of fine wire, whose ends are attached to a silver commutator carried on the shaft. Two light brushes with silver contact-pieces press against the commutator, and so make connection with the armature. An endless screw or worm, on the upper end of the armature shaft, engages with one of the wheels of the counting mechanism; and the number of revolutions of the armature is in this way recorded. On the right-hand side may be seen a plumb-bob for facilitating the upright fixing of the meter.

The fixed thick wire coils carry the main current, and the armature is joined up as a shunt across the mains, a high non-inductive resistance, fitted in the meter case, being connected in series with it. The fixed coils thus act the part of ammeter coils, while the current passing

through the armature is proportional to the volts at the terminals of the circuit. When the load is turned on, and the meter starts from rest, the motor will at once cause the brake disk to revolve with increasing velocity, until the drag due to the disk exactly counterbalances the torque due to the motor. It is evident, because of the drag being proportional to the speed of the disk, that this limiting speed at which the torque is balanced will be proportional to the load applied: and a further consideration will show that if the speed be always proportional to the load, the total number of revolutions of the disk will be proportional to the total energy supplied. In other words the resistance to rotation due to the disk increases with the speed, while the torque (§ 109) on the motor shaft at any given moment is proportional to the product of the currents in the armature and fixed coils, *i. e.* to the amperes and volts, or watts. Therefore the speed will be proportional to the watts. The total number of revolutions of the armature, counted up by the registering dials, is thus proportional to the energy which has been used, the dials indicating this in B. o. T. units. The fact that there is no iron in the meter, and consequently practic-

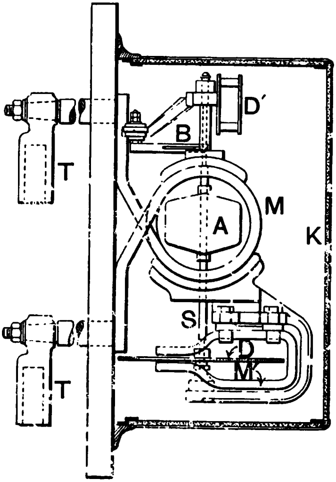


FIG. 133.—Elihu Thomson Meter (Side View).

ally no inductance, is the chief reason why the instrument may be used on both alternating and direct circuits.

Fig. 133 gives a side view of the disk *D* and spindle *S*, and one of the magnets *M′*. *M* shows the position of the fixed main coils, *A* is the armature, *B* one of the brushes, and *D′* the counting dials. *T*, *T* are the terminals, and *K* the cover.

This meter can be used on all kinds of non-inductive circuit, its construction and connection varying somewhat in different cases. Fig. 134 gives a diagram of the instrument and its connection on ordinary 2-wire direct- or monophase alternating-current circuits. Here *A* is the armature, and *C* the commutator, the retarding-disk and counting gear being omitted. *M* is the main coil and *R* the non-inductive resistance inserted in shunt (together with the armature) across the terminals of the supplied circuit at *T*, *T*. *C*, *C* is a *compounding coil* of many turns of fine wire wound concentrically with the main coils, and in such a direction as to help them in revolving the armature. It is connected up in the armature circuit, and its office is to compensate for the friction of the pivots and brushes, and enable the meter to start with a very small current.

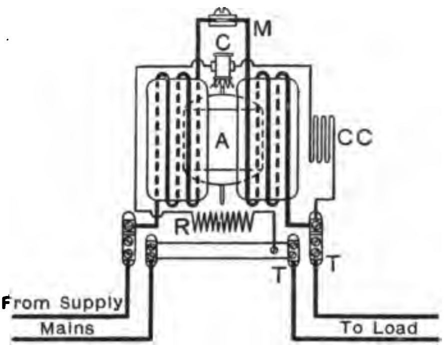


FIG. 134.—Connection of Elihu Thomson Meter to 2-wire Circuit.

On 3-wire circuits the two main coils are separately connected, one in each of the outer leads; while the shunt circuit is joined up between one of the outer leads and the middle wire, or else between the two "outers."

89. THE FERRANTI METER.—When a current-carrying conductor is placed in a magnetic field, at right angles to the lines of force, the conductor will move or tend to move across the field (§ 102). In Fig. 135, *C* is a movable con-

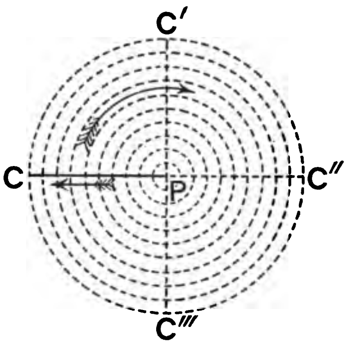


FIG. 135.

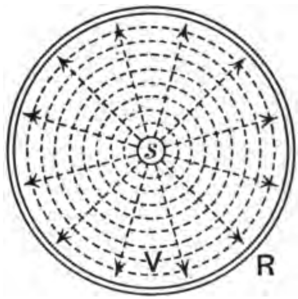


FIG. 136.

Principle of Ferranti Meter.

ductor pivoted at *P*, suitable arrangements being made to lead the current in at *P* and out at *C* without retarding the movement. The dots represent the lines of a magnetic field passing through the paper, the positive direction along the lines being upwards, let us suppose. Under these circumstances, the pivoted conductor will rotate in the direction shown by the curved arrow. If there were a number of other radial conductors, such as *C′*, *C″*, and *C‴*, all pivoted together at *P*, and carrying current

outwards, the tendency to rotate in the direction indicated would be increased. The direction of rotation may be deduced from the rule given in § 105; and if either the direction of the field or of the current in the conductors were altered, so also would be the direction of movement.

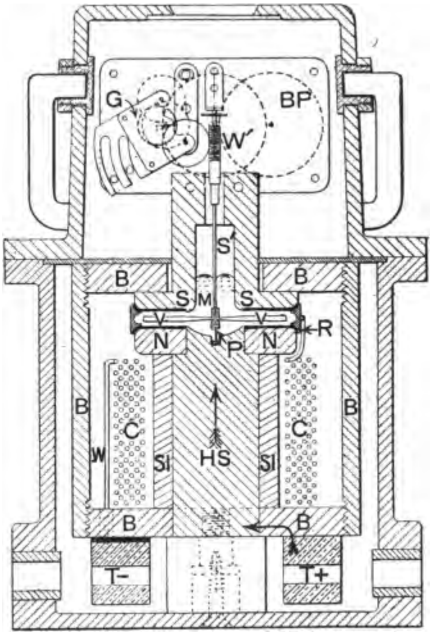


FIG. 137.—Ferranti Meter (Section).

The above example serves as an introduction to the principle of the Ferranti meter, this principle being more closely illustrated in Fig. 136. Here V represents a circular shallow vessel filled with mercury, the bottom being of insulating material, while the rim R is of metal. If one end of a circuit be connected with a metallic stud S, making contact with the mercury at the centre of the vessel, and the other with the metallic rim R, the current will flow out in all directions from S through the mercury to R, as indicated by the radial lines. If now a magnetic field be projected vertically

through the mercury bath, as indicated by the dots, the mercury, which may then be looked upon as a large number of radial current-carrying conductors pivoted at *S*, will rotate at a rate depending on the strength of the current and of the field.

This is the principle of the Ferranti meter, the rotating mercury communicating its motion to a kind of light paddle-wheel or fan floating in it, a worm on the spindle of the latter gearing with the registering-wheels. A section of the actual instrument is given in Fig. 137. *M* is the mercury trough, and *V*, *V* vanes fixed to a spindle *S′* pivoted at *P*, and geared with the counting-train above. This moving part is shown by itself in Fig. 138, and it will be noticed that there are four vanes, these being made of flattened nickel-steel wire, and varnished to prevent amalgamation with the mercury.

Returning now to Fig. 137, *C* is a coil of wire carrying the main current, the last turn of which is formed of the thin steel rim *R* acting as the circular wall of the mercury chamber. The mercury cup is mounted on the top of one pole *N*, *N* of a box electro-magnet energized by the coil *C*, *C*; this central core and coil being enclosed in an iron box, *B*, *B*, *B*, etc., the top of which, being brought close down to the surface of the mercury, forms the other pole of the magnet at *S*, *S*. Thus it is evident that a strong magnetic field passes vertically through the chamber containing the mercury. The current, starting from the terminal *T* +, passes up the centre core of the magnet, as shown by the arrows, to the middle of the mercury near *P*, whence it radiates on all sides to the rim *R*. It then passes round *C*, and *viâ* *W* to the insulated

terminal $T-$. The thick black lines above $T-$ and N, N, and below S, S, indicate insulation.

$B P$ is the back plate of the counting-train, the gearing connecting the latter with W being shown at G. This gearing is so arranged that the gear wheels may be altered to enable one and the same meter to be used at any given pressure. For the higher the circuit-pressure, the faster

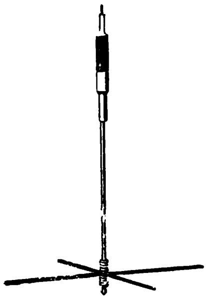


FIG. 138.—Ferranti Meter (Fan and Spindle).

FIG. 139.—Ferranti Meter (Exterior).

must the train run with a given current. One advantage of a series coil meter is that the winding needs no alteration for different voltages.

To give an initial field, and to ensure the meter starting with a small current, part of the magnet core is made of permanently-magnetized steel. Thus in Fig. 137, $H S$ is of hardened steel, and it is surrounded by a soft iron sleeve $S I$, $S I$. This is the arrangement for a 10-ampere meter.

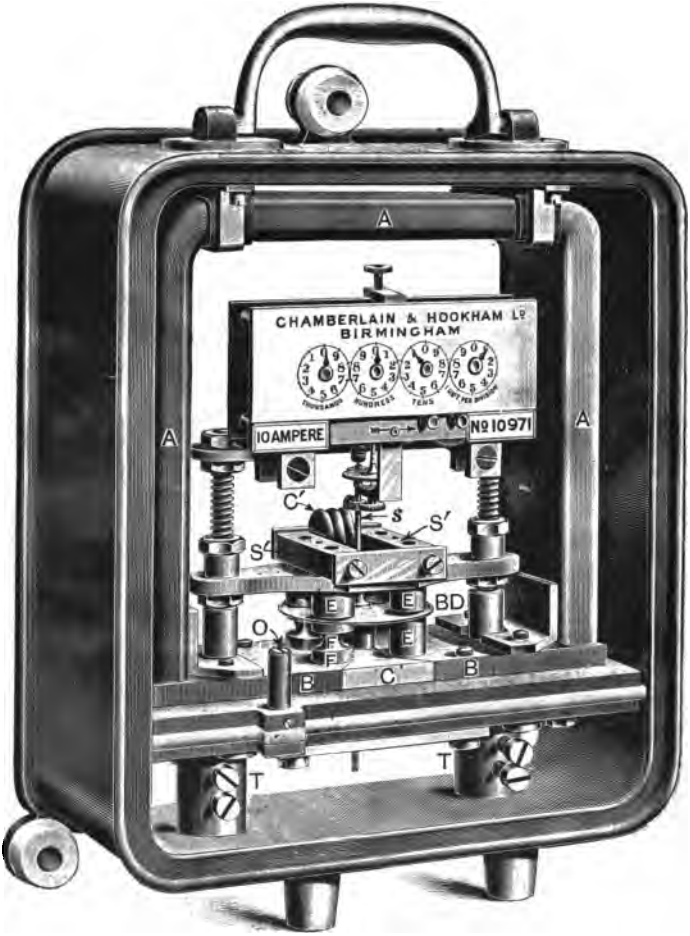


FIG. 142.—Hookham D.C. Meter (Interior).

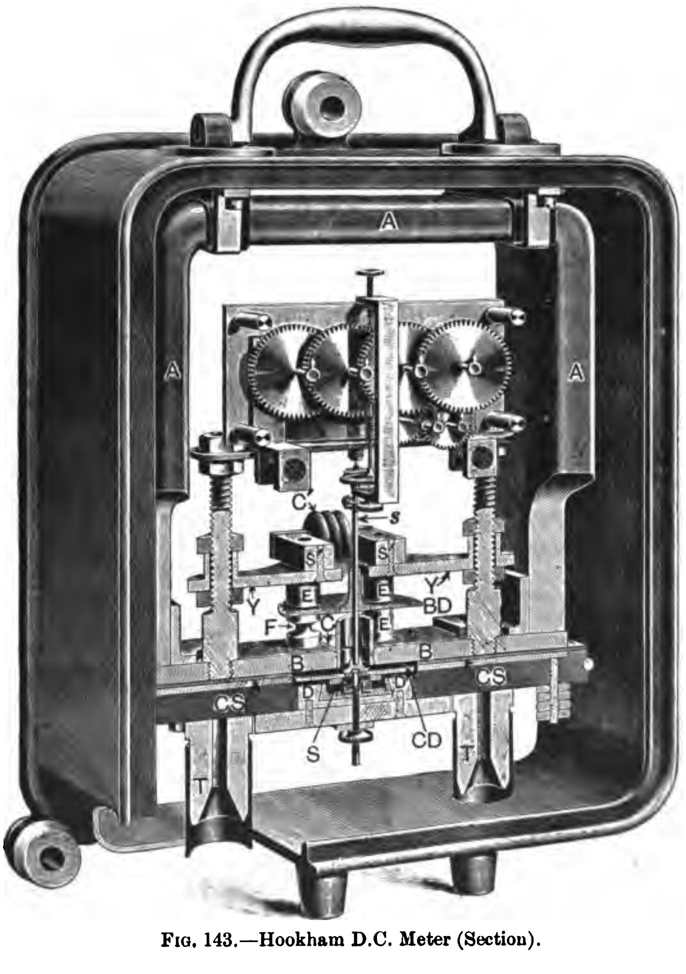


Fig. 143.—Hookham D.C. Meter (Section).

LL. Some of the lines complete their circuit through the iron bridge-piece *D, D,* and thus cut across the space *S* in which is the copper disk *C D* carried by the spindle *s*; the latter being connected at the top with the train of counting-wheels shown. The leads are joined-up with the terminals *T, T,* and the current flows from one to the other along the copper strips *C S, C S,* and across the space *S* and copper disk *C D*; the former being filled with mercury through the orifice closed by the screw at *O*. Except, of course, where the current enters and leaves by the copper strips, the mercury is carefully insulated from the fixed metal parts. We have thus the same condition of things as in Fig. 140, and it will be obvious that when current flows through the meter the disk will rotate at a speed proportional to the strength of the current. It will also be clear that such a meter will only work with direct currents.

If a copper or other non-magnetic conducting-disk be spun in a magnetic field whose lines pass through the disk from face to face, the latter will quickly come to rest owing to the retarding effect of the eddy currents set up in it. If the disk be kept in motion, it will experience a continual retarding or braking force due to these induced currents. This arrangement, which, in fact, may be looked upon as a magneto dynamo with its armature short-circuited, is known as a *Foucault brake.* This principle is used in the Hookham meter to retard or "damp" the rotation of the mechanism, and also, as will be remembered, in the meters described in §§ 87 and 88.

On the top of the pole-pieces *B, B* are four smaller ones in the shape of pillars *E, F,* three only of which can be seen in Fig. 142. Above these again, with a space between,

are four corresponding soft iron poles *E, E* fixed to a main support through which the lines pass. Thus the field of the magnet *A* completes its circuit partly below and partly above its poles *B, B*. Attached to the spindle is a second or brake disk *B D*, of copper or aluminium, which rotates in the field of the eight pole-pieces already mentioned: and eddy currents are set up in this with the result already described. It will be observed that the two left-hand lower pole-pieces *F* have a "neck" turned on them. The effect of this is to "throttle" the lines of force passing through them; that is to say, these poles keep saturated, and the braking force regular, even if the magnet *A* should suffer a slight diminution in strength in course of time.

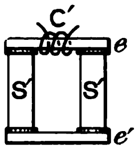


Fig. 144.

The four upper poles of the brake are mounted in pairs on two soft iron blocks *S′, S′*, supported on the brass cross-piece *Y, Y*. These blocks are connected at each end by iron cross-pieces, on one of which the coil *C′*, consisting of very few turns and carrying the main current, is mounted. The function of this coil is to diminish the brake force slightly, and so make up for the resistance to rotation offered by the "swirl" of the mercury in the mercury chamber. This "swirl resistance" increases as the square of the speed at which the disk is rotating; not as the first power of the speed, which is the law of the Foucault brake. In other words, if the speed of rotation were doubled, the resistance due to the mercury would be increased fourfold, whereas the braking action of the disk in the magnetic field would be only doubled.

A plan of *S′, S′*, and *C′* is given in Fig. 144, and from

this it would appear that the magnetic circuit of C' is so complete that it could exercise little or no effect on the poles below. As a matter of fact, however, the end pieces e, e' are separated from actual magnetic contact with S'', S'' by brass washers (shown shaded), the thickness of the latter being a matter of adjustment. The number of lines due to C'' which pass into S'', S'' depend on the adjustment of e; while with e in a given position, the effect on the pole-pieces and brake below is altered by more or less short-circuiting S'', S'' at e'. These, however, are matters arranged once for all by the meter tester. In any case, the coil C'', being so wound as to tend to weaken the polarity of the brake pole-pieces due to A, will exercise greater weakening effect as the current increases, *i. e.* as the speed of the meter and the "swirl resistance" of the mercury increases.

91. THE HOOKHAM DIRECT-CURRENT METER FOR SMALL CURRENTS.—To meet the demand for a small-current meter of less elaborate and therefore cheaper construction than that just described, the form shown in Fig. 145 has been introduced, this being suitable for small installations in which the total current demand does not exceed five amperes. The principle of action is very much the same as that of the form dealt with in the preceding paragraph.

The current to be metered is led in at the terminal + and out at the terminal −. From + it proceeds *viâ* the terminal G, and insulated wire W, into the mercury chamber H, down the cylindrical copper armature A, and out from the mercury through the insulated wire W', thence round the coil of the electro-magnet E'', and so to the negative terminal. W and W' are insulated by enclosure in

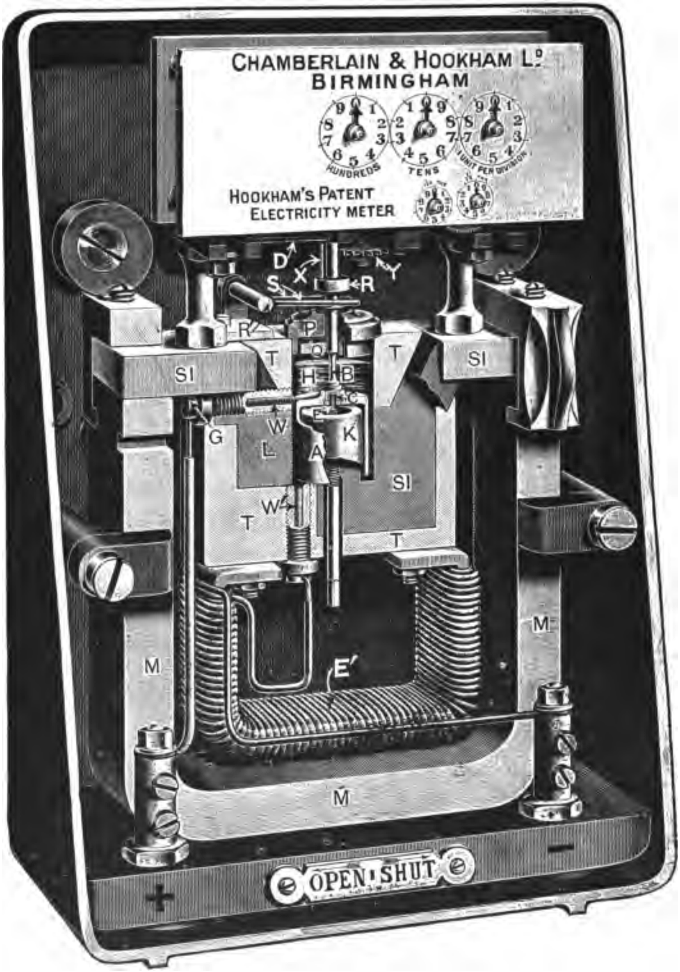


FIG. 145.—Hookham D.C. Meter for Small Currents.

ebonite screws. Except at the top and bottom edges, the cylinder armature, which is closed at the top, is plated with platinum. Platinum does not form an amalgam with mercury, and as a consequence the friction between the mercury and the rotating cylinder is very much less than it otherwise would be. The edges above mentioned do become amalgamated, however, and it is at these points that the current enters and leaves the armature; the current preferring to traverse this by reason of its superior conductance as compared with mercury.

The armature A is in the form of an inverted cup, and is mounted on the spindle B, turning on a jewelled bearing C, and held in position by the spring bearing D. The latter consists of a horizontal spring with a recess punched on the under-side of its free end, this recess forming a socket for the pointed top of the armature spindle. If left to itself, the mercury would float the armature off the jewelled bearing C; and to counteract this tendency the spindle B carries two balance-weights R and Q, which ensure that the armature shall just bear on the steel pivot E. By means of two fingers S, which are raised by turning the rod R' by means of a lever (not shown) which hangs down the front of the instrument, the armature may be lifted off the jewelled bearing during transit. The upper balance-weight R carries a vertical steel pin X, which drives the first wheel Y of the counting-gear. The mercury chamber is covered in at the top by the ebonite cap P.

M, M, M is a permanent magnet, the circuit of which is completed *viâ* the soft iron pieces SI, SI, SI, and between the poles K and L through one side of the arma-

ture. Most of the current, in passing from *W* to *W′*, traverses the left-hand side of the armature, from top to bottom, finding that an easier path than the mercury. In consequence of this and the strong magnetic field between *K* and *L*, the armature will rotate at a rate proportional to the current passing, and the supply will be registered by the counting-train. The parts *T*, *T*, *T*, *T*, are of antimony, this metal being very diamagnetic, and tending to keep the magnetic lines of force to their allotted path (Chap. *VI.*). The chief reason why this metal is used for these parts, however, is that it does not amalgamate with mercury. *A*, it should be noted, acts also as a brake.

The purpose of the electro-magnet *E′* is to compensate for the fluid friction of the mercury, and its retarding effect on the rotation of the armature. It does this by weakening the field in which the armature rotates, thus enabling the latter to exercise greater turning-effort, and to overcome the retardation due to the mercury. The speed with which the armature turns depends on the current passing through the meter, and the greater the speed the greater is the retarding effect of the mercury. Thus, as the latter increases, so also does the opposite action of the electro-magnet *E′*, which is excited by the main current.

The weakening of the field between *K* and *L* is effected by making the adjacent poles of *E′* of unlike polarity to those of the permanent magnet, this inducing some of the lines of the latter to complete their circuits *viâ E′* through the intervening antimony: while all tendency to weaken the permanent magnet is avoided. The poles of the electro-magnet being bent fairly close together, *E′*'s own field does not tend to stray upwards.

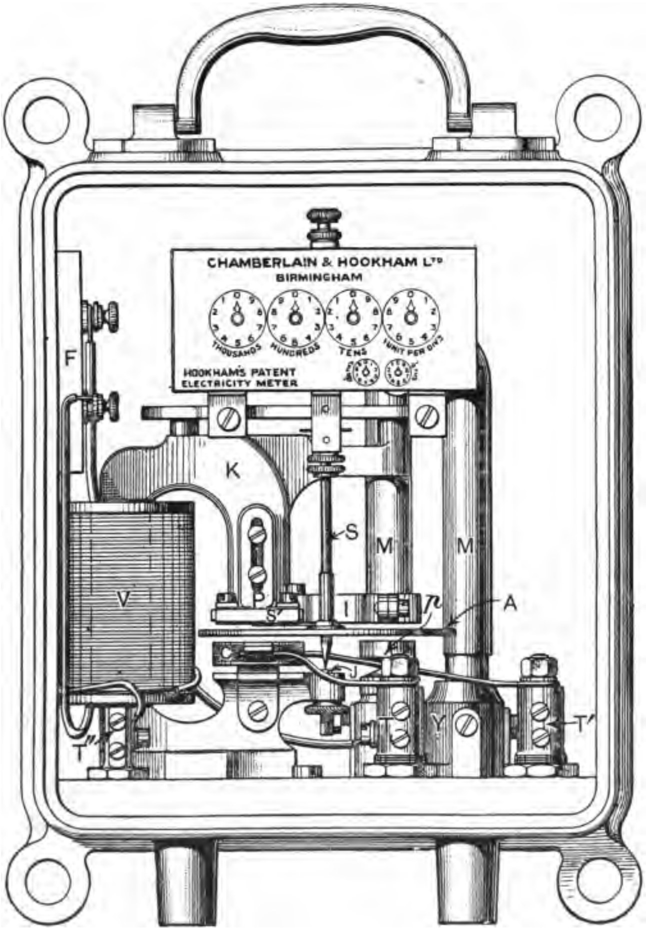
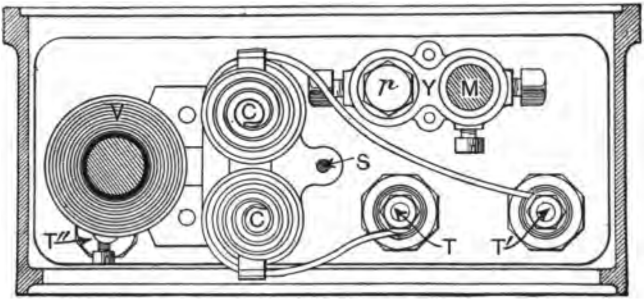


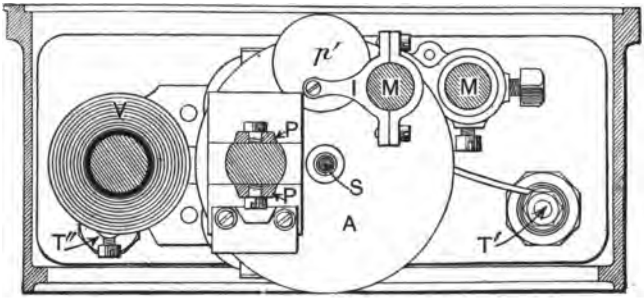
FIG. 146.—Hookham A.C. Meter.

92. THE HOOKHAM ALTERNATING-CURRENT METER.—In § 90 it was explained that if a conducting disk be spun



SECTION BELOW DISC A

FIG. 147.—Hookham A.C. Meter.



SECTION ABOVE DISC A

FIG. 148.—Hookham A.C. Meter.

in a magnetic field across the lines of force, it will experience a continual braking force due to the eddy currents induced in it. Conversely, a disk pivoted in a magnetic

field will be set in motion if the field be rotated. It is on both of these principles that the Hookham alternating-current meter works, the apparatus acting virtually as a single-phase induction motor, such as is described in §§ 136 and 137. It thus belongs to the class of motor meters.

This instrument, with cover removed, is shown in Fig. 146. The moving part consists of a vertical spindle *S*, running in a jewelled bearing *J*, and connected at the top with a train of counting-wheels. To this spindle is fixed an aluminium disk *A*, the rotation of which is effected in a manner about to be described. Below the disk are two flat coils *C, C*, connected in series with the terminals *T, T′*. Through these the main current passes. Fig. 146 gives a side view at *C* of only one of these coils, but they are both shown in plan in Fig. 147, in which the disk and upper parts of the instrument are removed to allow them to be seen. Fig. 148 is another plan, with the disk and upper pole-pieces in position.

V is a fine-wire or voltmeter coil connected as a shunt across the mains, its ends being joined to terminals *T″* and *T*. This energizes the core *K* with the adjustable pole-pieces *P, P*, and one of the latter carries a copper strip *S′*. A fuse is inserted in the circuit of the shunt-coil at *F*. By reason of the inductance of the shunt circuit, the current therein lags nearly 90° behind that in the main circuit; so that as a consequence the field due to the magnet *K* and pole-pieces *P, P* is out of phase with, and lags behind, that due to the main coils *C, C*. The way in which this causes the disk to rotate is difficult to explain in simple language, but we may say that eddy currents are first induced in the disk by the current in the main coils,

which are then immediately after acted upon by the field due to *K*, with the result that the disk is moved round: for it will be remembered that a current-carrying conductor placed in a magnetic field tends to move across it.

To prevent the disk turning at racing speed, it is necessary to have a retarding or braking force. This is supplied by the permanent horseshoe magnet *M*, one end of which is clamped in the cast-iron yoke *Y*, which supports a pole-piece *p* underneath the disk; while the other has clamped to it an iron arm *I* carrying an iron plate or pole-piece *p'*. The constant field between these pole-pieces passes through the disk and retards its rotation.

The rate of rotation of the disk is proportional to the watts being used at any given instant; and the counting-train registers the amount of energy consumed in B. o. T. units.

A simplified and cheaper form of this meter is supplied for currents up to 10 amperes.

93. THE ARON METER.—This, in its original form, was one of the earliest of clock meters; and since it was first introduced it has been improved from time to time, being now very extensively used. It must suffice to describe the latest form of the self-winding watt-hour or energy meter for 2-wire circuits, though it may be mentioned that there are various other types of Aron meter, for other circuits, and for special purposes.

The electro-mechanical principle upon which the action of the Aron meter is based may be explained by the help of Fig. 149. Here *C* and *C'* are two fixed coils in series, through which the main current is led *viâ* the terminals + and −. The fields due to these coils are indicated by

the curved arrows, and their polarity is as shown by the letters *N* and *S*.[1] Forming the bobs of two pendulums *P* and *P′* are the two flat coils *k* and *k′*, which are wound with a large number of turns of fine wire, and are connected in series with each other, and in shunt across the + and − leads of the circuit. Extra resistance, in the form of one or two fixed coils, is joined up in this shunt circuit.

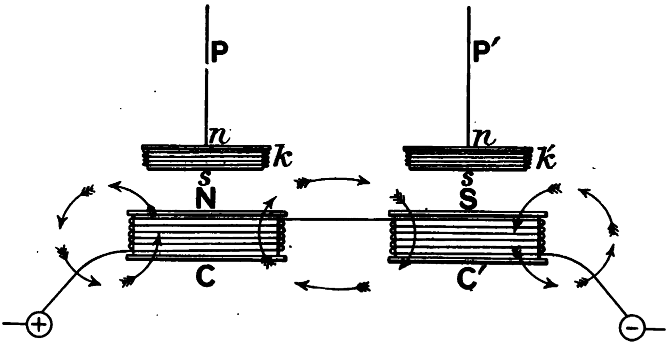


FIG. 149.—Principle of the Aron Meter.

The pendulum coils are wound to have similar polarity, as indicated by *n s*, *n s*.

As *C* and *C′* carry the main supply current, and *k* and *k′* a current which is proportional to the volts on the circuit, they constitute, respectively, the current and pressure coils which are to be found in every watt-hour meter. Considering the relative polarities of the fixed and swinging coils, it will be clear that the *N* pole of *C*, acting on

[1] The direction of the winding of the right-hand coil is wrongly drawn.

the *s* pole of *k*, will tend to bring it to rest; and will thus assist the action of gravity, and accelerate the oscillations of *P*. Those of *P′*, on the other hand, will be retarded; for the *S* pole of *C′* will repel the *s* pole of *k′*, and thus act against gravity, causing the oscillations of *P′* to be slower.

The forces acting on the pendulums at any moment are proportional to the watts being consumed, and the difference in rate between *P* and *P′* is communicated to the counting-dials through special clock-gear. As both fixed and moving coils have non-magnetic cores, their self-induction is very small; so that when an alternating supply is being measured, the relative polarity of the coils at any given instant is always the same.

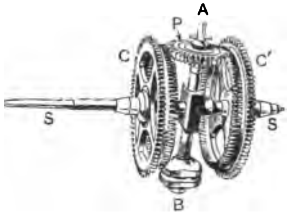


Fig. 150.—Aron Meter (Differential Gear).

The meter about to be described has two sets of clockwork, which are regulated respectively by the pendulums *P* and *P′* (Fig. 149); driving-power for both "clocks" being obtained from one spring, which is automatically "wound up" at frequent intervals by an electro-magnetic device. The clockwork is in motion all the time the meter is in circuit; even when no current is being used.

Before referring to the complete mechanism, attention must be called to the differential gear illustrated in Fig. 150; one such gear being employed to convey the driving-power from the common spring to the two sets of clockwork; and another to measure the difference in rate between the latter, and register the same upon the dials. In Fig.

150, the spindle *S, S* has an arm *A* fixed to it, this arm carrying at one end a loose pinion or planet-wheel *P*, and at the other a balance-weight *B*. Turning loosely on *S*, *S*, and gearing with *P*, are two crown wheels *C*, *C'*, which in their turn are connected with other portions of the wheel-work through the radial teeth cut on their circumference.

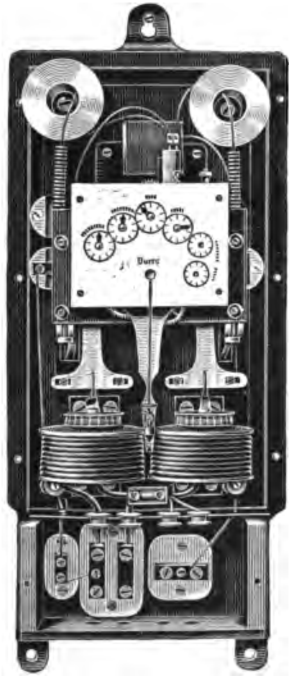


FIG. 151.—Aron Meter.

The spindle of one such differential gear is rotated by the electrically-coiled spring already referred to, and gives motion through *C* and *C'* to the two sets of clockwork. The two clocks drive the crown wheels of the second gear, and the difference in their speeds causes the pinion-shaft and *S*, *S* to rotate, this motion being directly communicated to the counting-train of the meter. In this second case it should be noted that the rotation of *S, S* is proportional to the *difference* in the speed of *C* and *C'*, which turn in opposite directions. Thus, supposing the two pendulums were oscillating at the same rate, there would be no movement whatever of *P* or *S, S*.

The actual meter, with cover removed, is depicted in Fig. 151. At the lower part, just above the terminal

blocks, will be seen the fixed main coils, and above these the smaller pendulum coils. The clockwork is all behind the registering-dials, and from the centre of the dial-plate

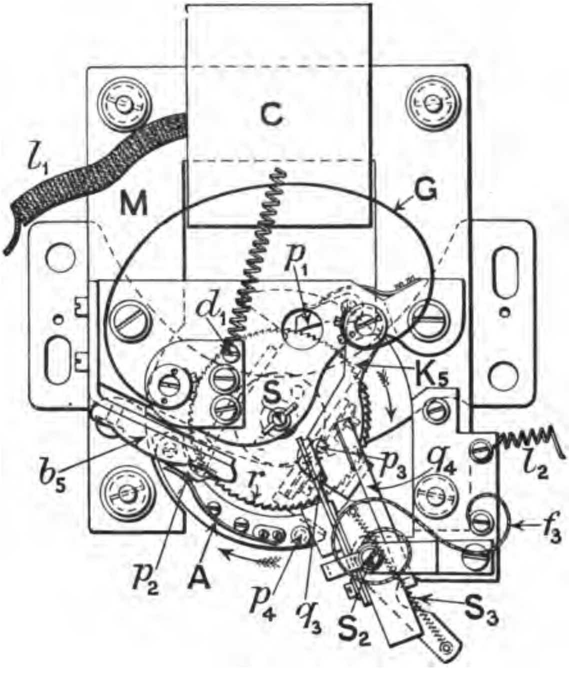


Fig. 152.—Aron Meter (Winding-Gear).

hangs a plumb-bob for enabling the instrument to be set perfectly vertical. Immediately above the dials will be noticed the actuating coil of the winding-gear illustrated in the next figure; and on the right and left of this are

bobbins carrying the extra shunt resistance which is joined-up in series with the pendulum coils.

In describing the apparatus in detail we will start with the electro-magnetic winding-gear, which is shown in Fig. 152.

This consists of a laminated electro-magnet *M* with one exciting-coil *C*, which is fixed on the yoke. In the gap between the pole-pieces of this magnet is an armature *A*, consisting of a Z-shaped, unwound laminated iron core, front and edge views of which are given in Fig. 153. This armature is only allowed to turn through an angle of about 75°, and is mounted loosely on the spindle *S*. When the magnet is excited, the armature rotates in the direction shown by the curved arrows; attraction in the opposite direction being prevented by cutting off the trailing horn or tip of the right-hand pole-piece of the magnet. The spindle *S*, about which the rotor turns, is directly connected with the arbor *K*, which drives the two clocks, and which is shown in Figs. 154, 155, 156, and 158.

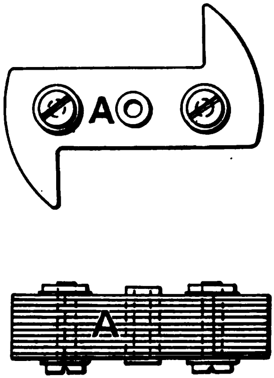


FIG. 153.—Armature of Winding-Gear.

The coil *C* (Fig. 152) is joined in shunt across the mains, and the current in it is only kept on for a fraction of a second, just long enough to enable the armature to turn through its appointed angle. The object of this operation is to put tension on the power spring *G*, the

right-hand end of which is fixed to a stud carried by the armature, while the other is attached to the framework. The ratchet-wheel r, which is attached to the spindle S, is prevented from following the motion of the armature by the pawl p_1; but during the slow return motion of the armature the pawl p_2, which is fixed to it, will cause r, together with the spindle S, to follow this motion. The spring G, which causes this return motion of the armature, thus rotates S and supplies the driving-power for the two clocks. During the short interval that the armature is winding up the spring G, the clocks are driven by the helical spring S_1 (Fig. 154), which also acts as a flexible connection between the spindle S and the arbor K (Figs. 154, 155, 156, and 158).

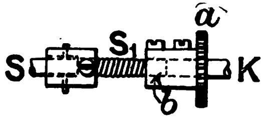


Fig. 154. — Piece connecting Winding-Gear and Clockwork.

The magnet current enters at l_1 (Fig. 152), passes through coil C to screw d_1, then through the spring G to the knee K_5 and contact-pin p_3 on A. From this it passes through the rocking contact-piece q_3 and flexible wire f_3, and out at l_2 to the shunt terminal of the meter. The magnet circuit is automatically closed and opened by the rocking contact-piece just mentioned. This consists of a fork with two prongs q_3 and q_4. The former is a nickel plate, and the latter is made of insulating material with a small nickel plate attached to it for the silver contact-pin p_3 to bear against when the circuit is open. The body of the fork is made of brass, and is pivoted on the centre S_2. The contact-pin p_3 is attached to but insulated from the armature, and during the winding-up movement of the latter it will press

against the prong q_3, thus allowing current to pass and at the same time forcing the switch-fork over to the left. Contact between p_3 and q_3 will be maintained, and the current will flow, until the centre line of the fork has passed the axis of the spring S_3; at which moment the fork will by S_3 be pulled further over to the left, q_3 leaving p_3, which will then bear against q_4, the circuit being thus broken. The contact between pin p_3 and the prong q_3 is a rubbing one, so that the surface of the contact is kept clean. The pin p_4 carried by the armature limits its motion in either direction, and it also ensures good contact between pin p_3 and prong q_3 at the proper time.

In the position shown in the figure, p_4 is bearing against an insulating block carried by the switch-fork, and the prong q_3 of the latter may be supposed to have just made contact with p_3. Current will then energize the magnet, and the armature will move rapidly in a clockwise direction, as shown by the curved arrows, until p_4 strikes against the fixed padded buffer b_5, tension being thus put on the driving-spring G. The circuit is then broken as above described, and the armature, etc., will slowly rotate in a left-handed or counter-clockwise direction until it again reaches the position shown in the figure, when the winding-up process will be repeated. When the meter is in action, this winding-gear comes into operation every half-minute.

As already mentioned, the actuating coil C and part of the magnet of the winding-gear (Fig. 152) can be seen just above the counting-dials in Fig. 151. In the direct-current meter, this coil is provided with an insulated copper sheath to lessen the sparking between p_3 and q_3 at

each break of the circuit. This it does by acting as a sort of secondary coil on which the lines of C collapse, and in which current is thereby induced. The inductance of C, and the sparking at the contacts due thereto, are consequently reduced.

We have now to see how the driving-power of the spindle S (Figs. 152 and 154) is communicated to the

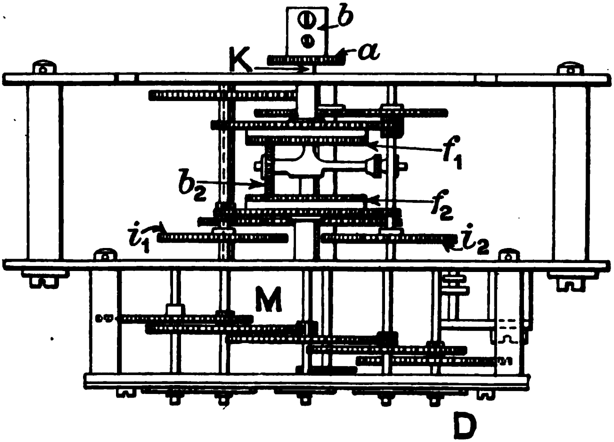


FIG. 155.—Aron Meter (Clockwork).

two clockworks or escapements governed by the two pendulums. The method of connection between S and K is shown in Fig. 154, and K may also be seen in Figs. 155 and 156, which give respectively a plan and elevation of the two escapements and the counting-train, the latter figure also showing the pendulums.

On the shaft K (Figs. 155 and 156) is mounted the planet-wheel b_2 of the first differential gear, which was

separately shown in Fig. 150. The two crown wheels f_1 and f_2 of this differential gear receive motion from b_2, and each is geared with a clock-train having an escapement and a pendulum. Thus f_1 is geared with escapement i_1, and f_2 with i_2; p_1 and p_2 being the two pendulums, which are pivoted at k_1 and k_2, and have coils k, k' for their bobs as already described.

The other end of each of the two clock-trains is connected with a second differential gear, which is mounted on the arbor q. The two crown wheels v_1 and v_2 thereof turn in opposite directions, and thereby move the planet-wheel q_1. v_2 is shown dotted as it is really in front of q_1.

If the two pendulums were to beat in unison, v_1 and v_2 would rotate at the same rate, and the arbor q would not be turned. But as pendulum p_1 is accelerated and gains n beats per second, while p_2 is retarded and loses n_1 beats per second; the speed of v_1 is increased, and that of v_2 diminished, in proportion to n and n_1 respectively. Hence the arbor will be turned with an angular velocity proportional to $n + n_1$. In other words, the motion of q will be proportional to the difference in rate of the two clock-trains. As the arbor q is connected with the counting-gear M, the registration on the dials D will be proportional to $n + n_1$.

The next part of the meter to be described, viz. its reversing-gear, of which no mention has been made so far, has for its object the elimination of the errors due to mechanical and electro-magnetic deviations of the pendulums. This is effected by reversing the current in the two pendulum coils every ten minutes, and at the same time reversing the connection between the clocks and the

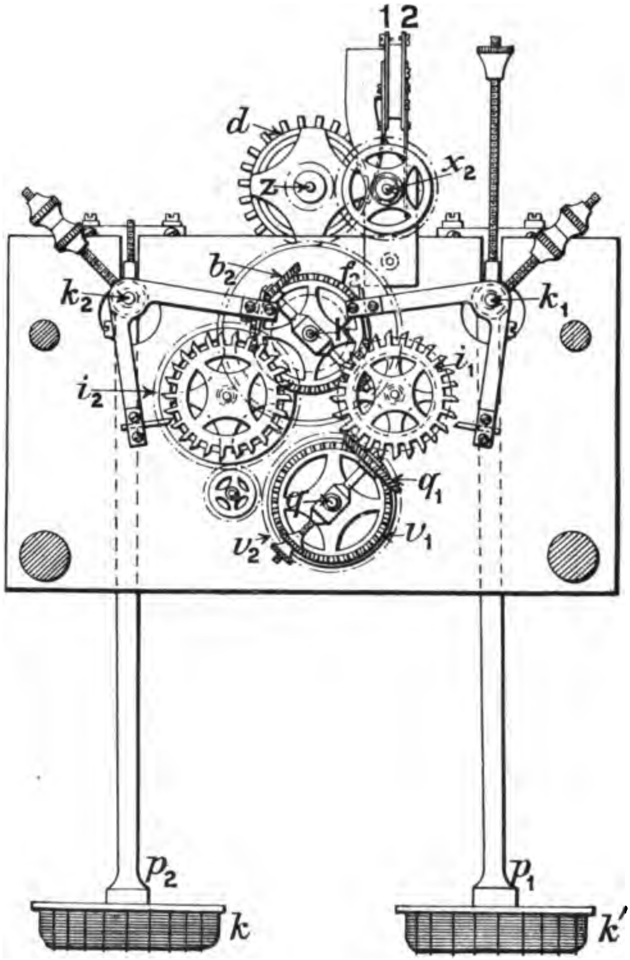


Fig. 156.—Aron Meter (Clockwork and Pendulums).

counting-train. The parts of the apparatus by which this object is attained are shown in Figs. 155 to 158.

Between arbors Z and K is a third one, not shown, which carries a wheel and a pinion. The wheel is in gear with pinion a, and the pinion with wheel d, which is loosely mounted on arbor Z. Wheel k_3 is fixed on Z and gears into pinion x_1, which, together with the reversing commutator x, is fixed on arbor x_2 (Fig. 158).

The wheel d carries a disk and crank-pin m_1, to which is attached one end of the watch-spring r, the barrel e of this spring being fixed on z. The wheel d is turned by the motion of arbor K, and causes the crank-pin m_1 to wind up the spring r; the latter being released, in a way to be presently described, three times during each revolution of d, the time between two consecutive releases being ten minutes. Every time r is released, the arbor Z turns through one-third of a revolution; while the arbor x_2 with the commutator thereon turns through one-half of a revolution.

There are four brushes, *1*, *2*, *3* and *4*, in contact with this commutator, *2* and *3* being connected with the small wires leading to the pendulum coils, and *1* and *4* with the shunt terminals of the meter. With the commutator in the position shown in Fig. 158, the current flows from one terminal through *4* to *3*, then through the pendulum coils back to *2*, then to *1*, and thence back to the other terminal. In the other position of the commutator, the current will go from *4* to *2*, then through the pendulum coils to *3*, and thence to *1*. The direction of the current through the pendulum circuit is thus periodically reversed.

The release of the spring r is effected in the following

manner. On the circumference of the disk carrying the crank-pin m_1 are fixed three equidistant pins w, w, each of which will, when it is in the right position, lift the

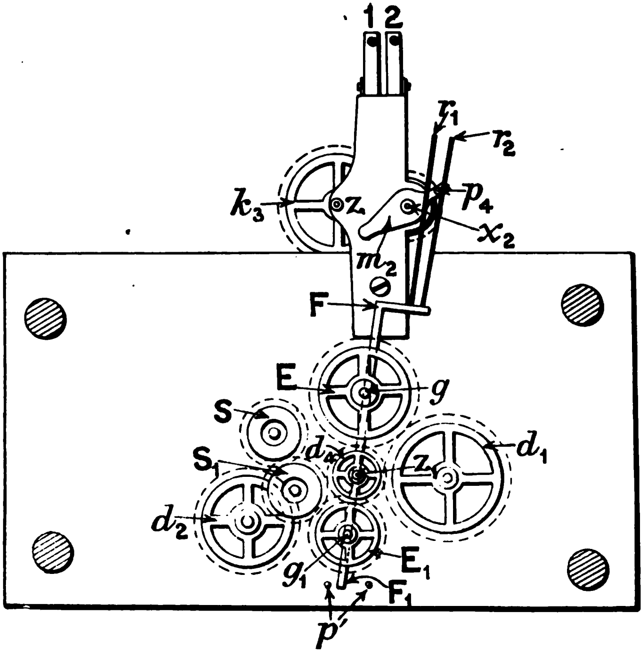


Fig. 157.—Aron Meter (Reversing-Gear).

lever l_1. Two of these pins only are shown in the figure. Lever l_2, which locks the arbor Z, and which is attached to the same arbor as l_1, will therefore also be lifted. Arbor Z will thus be unlocked, and the spring r will exert its

force and turn it, thus reversing the current in the pendulum coils.

With each such reversal of the current, which, as already explained, is for the purpose of eliminating errors, the pendulum which just before the reversal was retarded will be accelerated, and that which was previously accelerated will be retarded. Thus in two periods of reversal

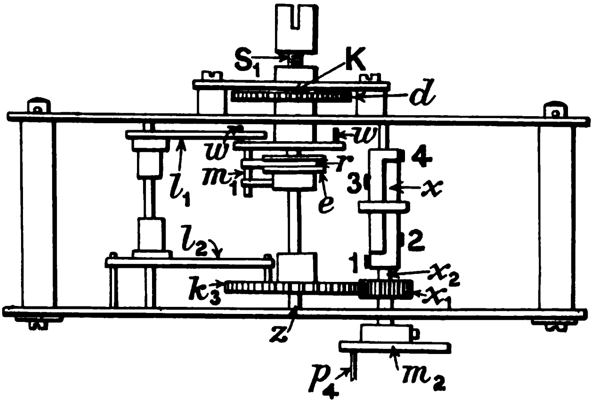


FIG. 158.—Aron Meter (Reversing-Gear).

the differential gear connecting the two clocks with the counting-train will turn first in one direction and then in the other. It thus becomes necessary periodically to reverse the connection of this differential gear with the counting-train, so that the revolution of the latter may always be in the same direction.

The mechanism for effecting this is chiefly shown in Fig. 157.

$F - F_1$ is a lever with its fulcrum at z_1, spindles g and

g_1 being fixed near the ends of this lever. These spindles carry the two loosely-mounted wheels E and E_1. On the bent end F of the lever are fixed two thin flat springs r_1 and r_2, and between these the pin p_4 of the crank m_2 is mounted. In the position shown this crank-pin presses against spring r_2, and the wheel E_1 gears into wheel S_1

At the next release of the watch-spring r (Fig. 158), the arbor x_2 will turn through half a revolution, and the position of the crank-pin p_4 will be diametrically opposite to that shown in Fig. 157. During this motion, the pin will press against spring r_1, and will throw the lever $F-F_1$ over and so cause wheel E to gear into wheel S, the wheels E_1 and S_1 being at the same time brought out of gear. The angular motion of lever $F-F_1$ is limited by the two stop-pins p'.

The small wheel d_4 is loosely mounted on the arbor z_1, about which lever $F-F_1$ turns; and this wheel is always in gear with wheels E and E_1. The wheel d_2 is fixed on the arbor q of the second differential gear (Fig. 156), and works into a pinion on the arbor of wheel S_1. d_1 is the first wheel of the counting-train, and it will be clear that it will continue to turn in the same direction, even if the direction in which wheel d_2 turns be changed, as the lever $F-F_1$ is thrown over at the same moment. The reversal of the current and the change in the position of the lever are effected simultaneously; the commutator and the crank m_2 being fixed on the same arbor.

The internal and external connections of the 2-wire Aron meter are given in Fig. 159; $S\ W$ being the service wires, and D the distribution-board. T, T' are the main and t, t the shunt terminals, one of the latter being

connected to the adjacent main terminal, with a fuse *F* interposed. *C* and *C′* are the fixed main coils, which are shown also in Figs. 149 and 151; and *k* and *k′* the pendulum coils, the two wires leading to each of the latter running down alongside each pendulum rod. *R* and *R′* are the extra resistances inserted in the pendulum circuit; and the reversing-switch *R S* stands for the reversing-commutator above described. *M* is the coil of the electro-magnet operating the winding-gear, this, it will be noticed, forming a second shunt circuit across *S W*.

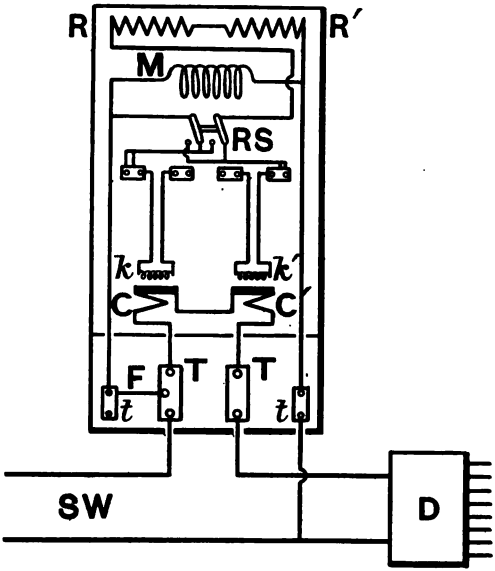


FIG. 159.—Connection of Aron Meter to 2-wire Circuit.

It might be thought, from the length and detail of this description, that the Aron meter was an extremely complicated piece of apparatus, and one very liable to get out of order; but such is not really the case, as may be gathered from the extent to which it is used. It is evidently not nearly so simple as some of those previously described,

but it has many advantages, and is very reliable in its indications.

94. The Johnson and Phillips Meter.—This clockwork meter, which is for use on direct-current circuits, acts on what is known as the intermittent integrating principle; the value of the current passing being taken every half-minute, and the successive values duly integrated or added up, and registered by the counting-gear. The mechanism may be divided into three parts, viz. :—

(*a*) An electrically-started and operated pendulum.

(*b*) An ammeter.

(*c*) The integrating mechanism and counting-train.

Fig. 160.—Johnson and Phillips Meter (Exterior).

An external view of the meter is given in Fig. 160, the ammeter pointer and scale being seen at the top, and the counting-dials below. The centre pointer of the latter indicates Board of Trade units and tenths of a unit on the large scale, and the five smaller dials respectively 10s, 100s, 1000s, 10,000s, and 100,000s. This meter differs from all others described here, in that the ammeter enables the demand at any given time to be noted.

Figs. 161 and 162 give front and back views respectively of the interior. *P* is an aluminium pendulum rod pivoted at *p*, and fitted with a lead bob *L*, the height of which is adjusted by means of the nuts *N*. The pendulum rod carries a roller *R*, which is embraced by a piece of bent wire *W* fixed to the

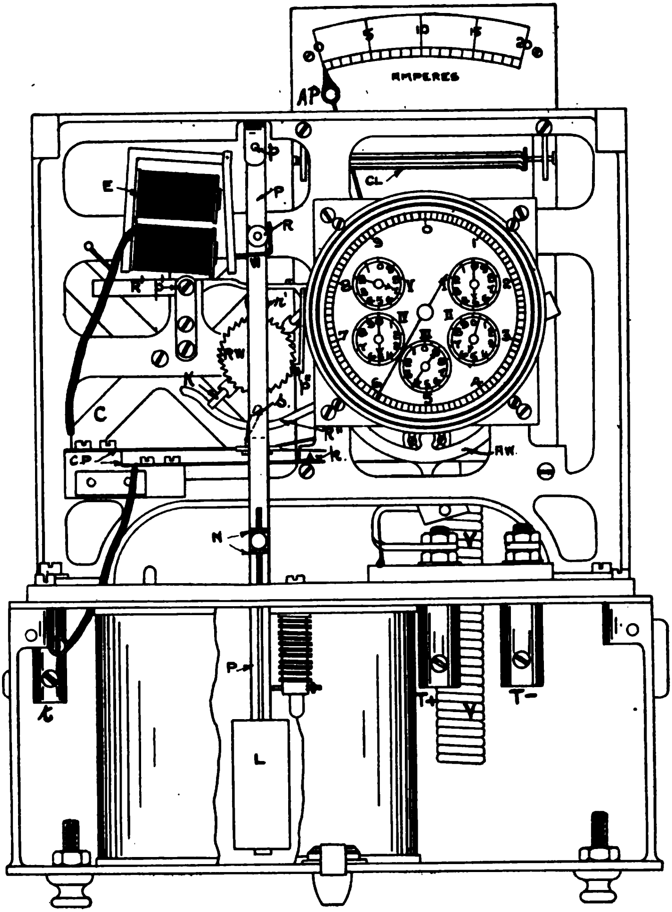


FIG. 161.—Johnson and Phillips Meter (Interior).

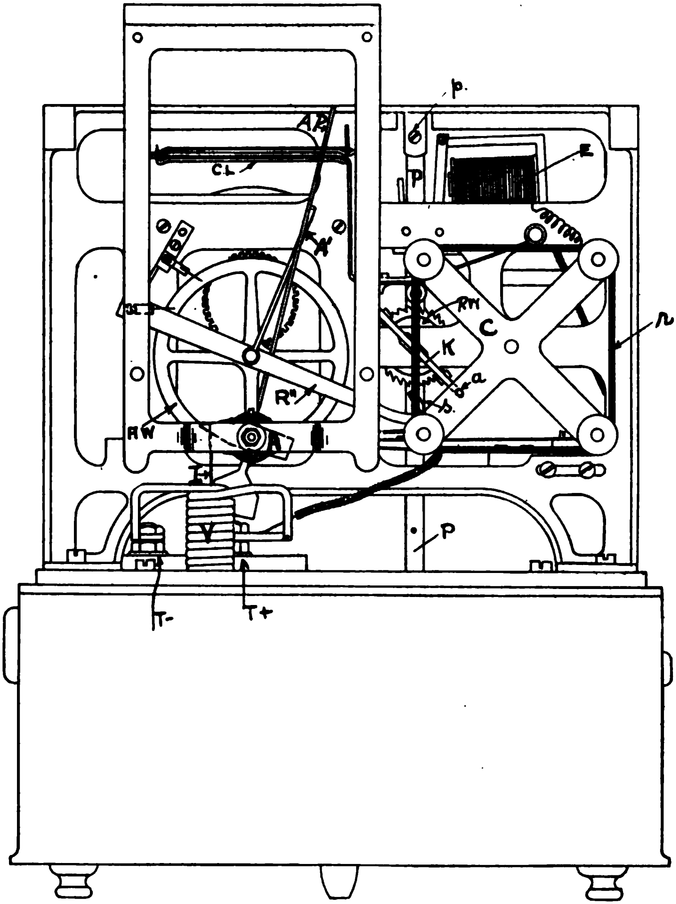


FIG. 162.—Johnson and Phillips Meter (Interior).

loosely-hinged armature of the electro-magnet *E*. The coils of this magnet, together with the extra resistance *r*, which is wound round insulating supports on the arms of the cross-piece *C*, are joined up in shunt to the opposite leads of the supply mains, through the terminals *t* and *T* +; *T* + and *T* − being the main terminals. Between *E* and *t*, however, is interposed an ingenious make-and-break device operated by the pendulum itself; current being periodically sent through *E*, causing the armature to be attracted, and *W* to give a fresh impulse to the pendulum. This make-and-break consists of two contact springs *C P* making contact at *k*, the upper spring carrying a block which, according as the pendulum is oscillating at or less than its normal amplitude, is either passed over or depressed by a steel toggle *s* pivoted on the pendulum rod.

The details of this arrangement are more clearly shown in Fig. 164. Here *k* is the point of contact between the two springs *C P*, *P* the pendulum rod, *s* the steel toggle, and *B* the block fixed on the top spring; four positions of these being shown, as at (*a*) to (*d*). The block *B*, it should be observed, has a raised edge *e* on the right-hand side, and a notch *n* on the left-hand side. Before the meter is connected to the circuit, and unless the pendulum is held on one side by a clutch provided for the purpose, for use when moving the meter; or when it is purposely put out of action; the state of things is as at *a*, the toggle catching in the notch and forcing the springs together. When the meter is connected with the circuit, current will pass round the electro-magnet, and the pendulum will be set swinging in the way already explained. As long as the necessary amplitude of swing is maintained, the toggle

will simply slip backwards and forwards over the block *B* without depressing it, as at *b* and *c*. When the pendulum is coming to rest, and *s* will not slip past *e* on the swing

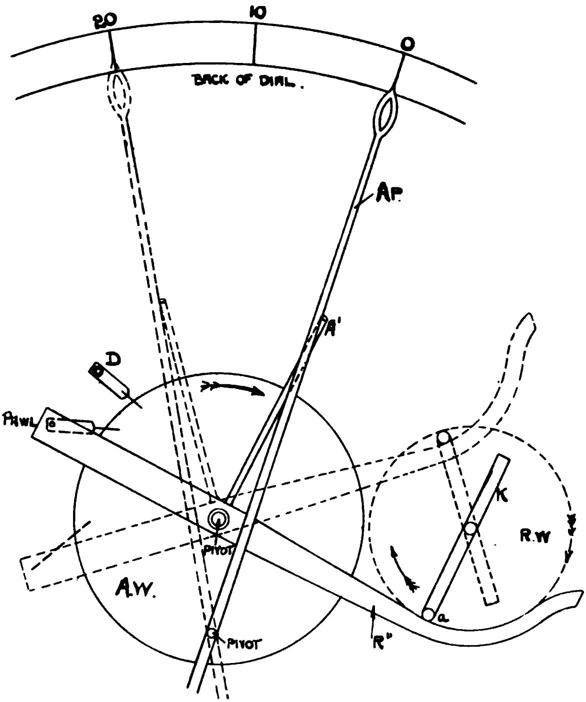


FIG. 163.—Johnson and Phillips Meter (Details).

to the right, it will engage in *n* on the swing to the left, thus forcing the springs together, and causing another momentary impulse current to flow. These impulses take place every few seconds,

The swinging of the pendulum operates a rocking lever R' pivoted at p', by means of a roller r' (Fig. 161). At the right-hand end of the lever hangs a pawl p'', engaging with the ratchet-wheel $R\ W$. When the pendulum swings to the left, the pawl drops and engages in the next lower tooth of the ratchet-wheel; and when it swings to the right, r' forces p'' up, and $R\ W$ round. The latter consequently moves forward one tooth with every complete swing of the pendulum; and as the wheel has thirty teeth, and the pendulum beats seconds, $R\ W$ consequently makes one complete revolution every half-minute. Fixed on the same spindle as $R\ W$ is a crank K which operates the integrating mechanism, in a way to be presently described.

The ammeter consists of a vertical coil of thick wire V connected between $T+$ and $T-$. Suspended from one end of an aluminium cross-bar or beam A, is a piece of thin iron wire I, which acts as the ammeter armature. A and the ammeter pointer $A\ P$ are fixed on a horizontal steel spindle set in jewelled bearings. At each end of the spindle is fixed a fine spiral spring of phosphor bronze; the tendency of these springs being to draw the armature I out of the coil, and keep the pointer at the zero position. It is against this tendency that the ammeter current acts.

The integrating mechanism is shown separately in Fig. 163, as it can only partly be seen in Figs. 161 and 162. Here $R\ W$ and K are the ratchet-wheel and crank already referred to, and $A\ P$ is the ammeter pointer. R'' is a rocking lever, which at its heaviest end carries a notched pawl engaging with the smooth edge of the aluminium wheel $A\ W$, which may be considered as the first wheel of the counting-train. This pawl forces $A\ W$ in a right-

handed direction, as indicated by the curved arrow; its movement in the reverse direction being arrested by the notched detent *D*. Fixed at right angles with *R''* is an arm *A'*, the bent end of which bears against the side of the ammeter pointer *A P*. *K* has an arm *a* at one end, and every half-minute this bears against the upper side

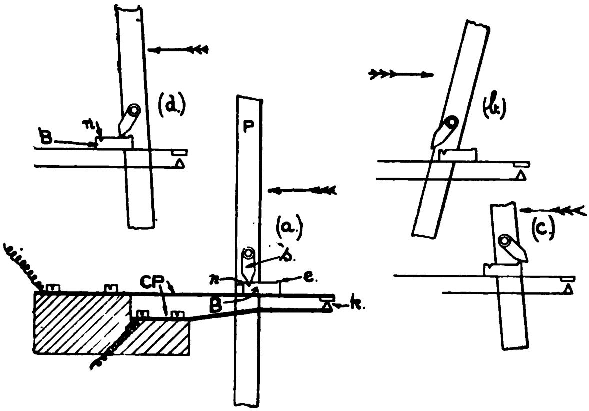


Fig. 164.—Johnson and Phillips Meter (Details).

of *R''*, and moves it to its zero position; the extent of this movement depending on the position of *A P*, that is to say, on the current passing; and being registered by a corresponding movement of *A W* and its counting-gear.

Starting from the firm line position of *A P* shown in Fig. 163, we will suppose that the current deflects it to the extent of twenty amperes, as indicated by the dotted position. As *a* moves round, the curved end of *R''* being the lighter, rises; and *A'* follows *A P* to its deflected position. As *a*

moves down on the right from its dotted position, it bears on R'', and forces it down again to zero. The revolving crank K also operates a clip $C\,L$ (Figs. 161 and 162) which alternately locks and releases $A\,P$. Thus, to start with, $A\,P$ is free to indicate the passing current, it is then locked by $C\,L$ to prevent A', which is following it up, from moving it over further. Then A' having, so to speak, noted the deflection of $A\,P$, and R'' and the pawl being moved back in order to record the same; $A\,P$ is released for a few seconds to enable it to take note of any variation of the current, and is then clamped once more.

This cycle of operations takes place every half-minute, and the action of the integrating mechanism may be otherwise explained, by saying that the counting-train is operated twice every minute, to an extent proportionate to the ammeter deflection at the time being.

If no current be passing in the main circuit, the ammeter needle remains at zero, and no movement of R'' or of the counting-train takes place. The pendulum, however, is swinging all the time, as the shunt circuit is permanently connected to the + and − leads. An apparent improvement would be to insert an extra contact in the shunt circuit, which would remain open so long as no current was being used, and thus obviate needless wear and tear of the pendulum mechanism. This, however, has been tried, but without success, the sensitiveness of the meter on light loads being reduced thereby.

95. SPECIAL METERS.—The meters already described, when used on 3- or 5-wire systems, are connected in circuit in a special manner, or else modified in construction. Alternating-current meters, when employed on polyphase

circuits, also need special connection or modification. Their functions as energy or quantity meters, *i. e.* as watt-hour or ampere-hour meters, however, remain unchanged.

There are a few special kinds of meter, some of which may be briefly described here. The *hour meter* is virtually an electrically-actuated clock, which simply records the number of hours the current has been used, without taking into account the value of the current, or any variation thereof. Such are sometimes employed in cases where the number of lamps alight is practically constant; as in small offices, hotel bedrooms, etc., or in connection with motors. These meters are naturally less expensive than quantity or energy meters.

When the supply is charged for at two rates, according as the consumption takes place during the hours of light or heavy load; *2-rate* or *day and night load* meters are made use of. The counting mechanism is driven at a lower rate during the light load hours, and at a quicker rate during those of heavy load. The difference between the two rates is proportional to the difference in the charges, the units indicated by the counting-gear being charged at one uniform price.

Battery meters are for use with secondary batteries, and are arranged in various ways. In one form, a pointer moves in one direction over a scale during charge, and in the opposite direction during discharge, indicating either ampere hours or B. o. T. units. Thus the condition of the battery during charge or discharge may be seen at a glance. Another type of battery meter has two sets of dials, one indicating the number of units absorbed in charging, and the other the number given out on discharge.

This latter arrangement may also be effected by joining up two ordinary meters in series, but in opposition; one meter being actuated only by the charging current, and the other only by the discharging current.

*96. THE MAXIMUM-DEMAND SYSTEM OF CHARGING.—What is known as the *maximum-demand system* of charging for electricity supply, is very largely adopted all over the country, and bids fair to become the standard method of charging. According to this system,[1] a certain number of the total units registered by the ordinary meter are charged for at a first or full price, and the remainder at a second or reduced price. The number to be charged at the full price is the greater, the greater the maximum current that has ever been used by the consumer at any time during the quarter; and depends also on whether the full-priced consumption is to average ½, 1, 1½ or more hours per day, this varying in different towns and districts.

As an example, suppose that during one quarter's working, a consumer drew a maximum of 6 amperes through his meter. If the supply pressure is, say 250 volts, this is equivalent to 1500 watts, and represents his maximum power-demand. If, in his particular town or district, the rule is that the maximum demand shall average 1½ hours per day; multiplying 1500 × 1½ gives 2250 watt-hours, or 2¼ Board of Trade units as the daily average. Taking the 91 days in a quarter, 2¼ × 91 or 205 will represent the number of units to be charged at the first price. Suppose the full price is 7*d.* and the reduced price 2*d.*, and that

[1] For a fuller explanation, the reader may be referred to an article by the Author in the *Electrical Review* for March 2, 1900, p. 370.

his total consumption during the quarter was 319 units, his bill will then be as follows :—

	Units.		£	s.	d.
Total consumption	= 319				
Units at 1st price	= 205	@ 7*d.* =	5	19	7
Units at 2nd price	= 114	@ 2*d.* =	0	19	0
		Total ..	£6	18	7

In his *Electric Wiring Tables*, the Author gives a special table for facilitating the apportioning of the units consumed at the first and second prices respectively.

Instruments for registering the greatest current ever taken during any given period are called *maximum-demand indicators*, or simply *demand indicators*; and two forms of such are described in the following paragraphs. Such are also termed *rebate indicators*, from the fact that the rebate or reduction in the charge for supply depends upon their indications.

*97. THE WRIGHT DEMAND OR REBATE INDICATOR.—This is an instrument for ascertaining a consumer's maximum demand, as required by the system of charging just described. Its indications are brought about by the heating effect of the current, and it is consequently available for use on both alternating- and direct-current circuits.

The essential parts of the apparatus are illustrated by the sketch in Fig. 165. Here *T*, *T* is an hermetically-sealed U-tube, with bulbs at *B* and *B′*, and a branch tube *t* ; *T T* being partly filled with sulphuric acid. The main current entering and leaving by the terminals *TE*, *TE*, passes round a heating strip *H* of high-resistance metal, the

latter making one or more turns round the bulb *B*, according to the range of the instrument. When current passes, the air in *B* is heated and expands, and the liquid is forced down the left-hand leg of the U-tube, and up the right-hand one, till at length some of it overflows into the registering-tube *t*.

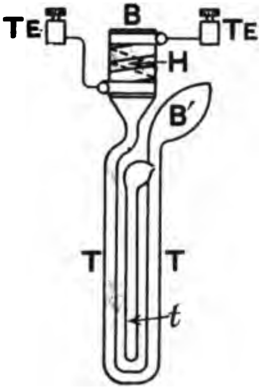


FIG. 165.—Diagram of Wright Demand Indicator.

Suppose that early in the quarter a current of five amperes passes round the circuit, *B* will heat up to a certain extent, and a proportionate amount of liquid will overflow into *t*, and will remain there. As long as the future demand does not exceed five amperes, there will be no further overflow into *t*; but if on a certain night the maximum demand reaches, say, seven amperes, more of the liquid, equivalent to the extra two amperes, will run over into *t*. Thus it will be clear that if the indications of the instrument are taken, say, once a quarter, the amount of liquid collected in *t* will be proportional to the maximum current that has ever been used at any time during that period.

The actual instrument, open and closed, is shown in Figs. 166 and 167 respectively. At the top are the terminals, and below these the flexible connections leading to the heating strip on the left-hand bulb. This heating strip, by the way, is different in form from that in Fig. 165. Its resistance, and consequently its shape, depend on

the current it is destined to carry, and on the circuit

Fig. 166. Wright Demand Indicator. Fig. 167.

voltage. The U-tube is hidden by a cardboard scale, on

which, on one side, the maximum current that has passed may be read off; while on the other, the number of B. o. T. units chargeable at the first price (§ 96) is indicated; the reading being taken at the level of the liquid which has overflown. Special flexible or hinged connections with the terminals enable the instrument to be tilted up by the meter inspector, after he has taken the quarterly reading. The liquid in the overflow tube in front of the scales then flows out first into the right-hand bulb, and afterwards down into the U-tube, and the instrument is ready for a fresh indication. In the left-hand figure, it will be noticed, for example, that the liquid in the overflow tube indicates a maximum demand of nearly 24 amperes.

A demand indicator should not be too prompt to act, that is to say, the consumer should not be penalised for any little increase of consumption lasting only a few minutes. The ordinary Wright Demand Indicator takes about ten minutes to register any increase in the current. For special purposes, such as in motor installations, the sluggishness of the instrument is further increased by enclosing the heating bulb in a cylinder of iron; so that the heating strip has to heat up this cylinder as well as the bulb and tube and the air inside, and the liquid is less quickly acted upon.

A demand indicator fitted in the same case as a meter, was illustrated in Fig. 125.

98. THE THREE-WIRE WRIGHT DEMAND INDICATOR.—On 3-wire circuits it was usual to fix two indicators, one on each outer conductor; the maximum demand registered by each being taken separately when separate meters were used, and added together when a 3-wire meter was employed.

A single instrument for 3-wire work has now been introduced; and this, besides being cheaper, gives a fairer indication, as the loads on each side of a 3-wire system are generally more or less unequal.

The connections of this instrument are shown diagrammatically in Fig. 168. Here *H* is the heating strip, which is connected where the two sides of the system branch in to the middle or neutral conductor; the latter being joined up through resistance strips *A B* and *A C*. Most of the current flowing from one side of the system to the other passes *viâ* *B A C*, and the remainder through *H*. *H* may consequently be regarded in the light of a voltmeter coil, and the heating effect therein is obviously proportional to the square of the P.Ds., between *B* and *C*. The greater the number of lamps alight (presuming them to be quite equally divided between the + and − sides), the greater will be the P.D. between *B* and *C*, and the greater the heating effect. We have now to show that the indication of the instrument, with a given number of lamps, is the same whether the latter are equally or unequally distributed on the two sides of the system. The P.D. between the two outers (+ and −) is, of course, practically invariable; but that between *B* and *A*, and between *A* and *C*, varies directly with the number of equal lamps on each side. If there are 60 lamps alight altogether, 30 on each side, the potentials *B A* and *A C* will be equal, *i. e.* as 30 : 30. If there are 40 lamps on one side and 20

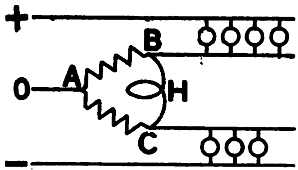


Fig. 168.—Connections of Wright 3-wire Demand Indicator.

on the other, potentials *B A* and *A C* will be as 40 : 20. If there are 50 lamps on one side and 10 on the other, potentials *B A* and *A C* will be as 50 : 10. In each case, the sum

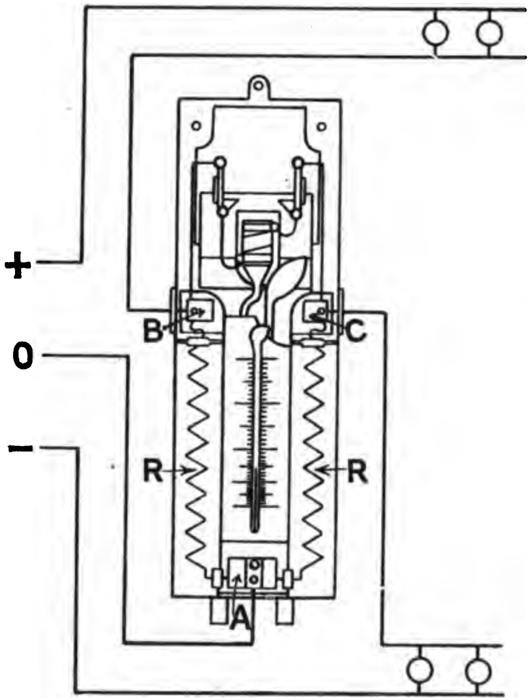


FIG. 169.—Wright 3-wire Demand Indicator.

of the P.Ds. is equivalent to 60; and the registrations of the demand indicator will be the same. A diagram of the actual instrument is given in Fig. 169. Here *R, R* are the resistances between the terminals *A B* and *A C*;

otherwise the apparatus is practically the same as that in Figs. 166 and 167.

99. THE ATKINSON-SCHATTNER DEMAND INDICATOR.—This instrument, the actuating portion of which is similar in principle to that of the gravity ammeter illustrated in Chap. *VII.*, is suitable for both alternating- and direct-current circuits. As will be seen from Fig. 170, the moving portion carries a glass tube having a certain number of balls in it; the remaining space in this tube, which is bent to the peculiar form shown, being filled with glycerine. Above the curved horizontal part of the tube, an ordinary ammeter scale is arranged; so that the instrument combines the function of an ammeter with that of a maximum-demand indicator. The reading on the ammeter scale is indicated by the pointer fixed to the case, the scale-card forming part of the moving portion. The instrument is set to zero by means of the brass-ball adjustment seen on the right, all the balls to start with being in the top circular part of the tube, to the left of the pointer.

The current going through the instrument deflects the moving portion to a proportionate extent, and if the deflection is maintained more than two minutes, one or more of the balls will slowly roll down, eventually falling into the straight leg of the tube. The number of balls released depends upon the current passing, and is the record of the maximum demand. A scale is arranged by the side of the lower leg, which shows at a glance the number of balls down, the rebate corresponding with this being given on a table beneath the upper part of the tube. In the illustration, a maximum current corresponding to

four balls down has already been registered, and a further increase is about to take effect. The action of the balls is certain and slow, so that whilst swinging or a sudden instantaneous short circuit does not give them time to move, any increase of current lasting for more than two minutes will be recorded.

The glass tube is easily taken out by hand, as it is only

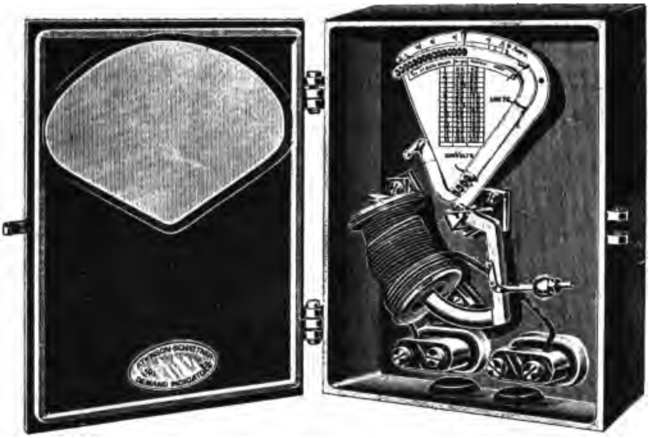


FIG. 170.—Atkinson-Schattner Demand Indicator.

held in position on the card by horseshoe clips; and the instrument can be reset by removing the tube, turning it upside down, and returning it to the clips. The apparatus is fitted in a cast-iron case, the outside dimensions of which are $7\frac{1}{2}'' \times 8'' \times 2\frac{1}{2}''$; and the hinged front is provided with a window through which the indications can be read. In recent forms a spare tube is fixed inside the door of the case.

CHAPTER XIII.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Define a kilowatt and a Board of Trade unit of energy. Explain clearly the difference between them, and describe in detail, with sketches, the instruments which are commercially employed in measuring these two quantities. [Prel. 1900.]

*2. Explain the difference between a wattmeter and a watt-hour meter.

*3. Describe briefly and concisely the duty of an electricity meter.

4. Distinguish clearly between an ampere-hour and a watt-hour meter; and say which would be most reliable on a circuit in which the pressure was subject to variation, and why.

*5. Which do you consider the most convenient method of classifying meters?

6. Describe briefly any kind of supply meter with which you are familiar. What types of meter are most likely to register with small loads? Give reasons. [Ord. 1896.]

7. What is meant by electro-chemical deposition? Explain any form of electric meter which depends upon this effect, and state how, by means of two slips of lead and a little acidulated water, you can find out which is the positive brush of a continuous-current dynamo. Ord. 1890.]

8. Draw and describe any practical form of electric quantity meter. What is a Board of Trade unit? [Ord. 1891.]

9. Show that the indications of the Bastian meter are not affected by the size and distance apart of the platinum plates. For what reason is it necessary that the latter should be fairly large and close together?

10. In the Schattner prepayment meter, the weights which the inspector places in lieu of the coins, are either less or greater in weight than the latter, according to which scale pans are used for the coins and for the weights respectively. Why is this?

11. Could the mercury reservoir and syphon tube be dispensed

with in the Wright meter? If so, how would the meter be affected? Sketch an arrangement with these alterations carried out.

12. Describe in your own words the action of the Shallenberger meter.

13. Explain the principle of the Elihu Thomson meter, and show, by sketch and explanation, how the copper disk revolving between the poles of the magnets produces a retarding effect upon the revolutions of the coil.

*14. Show by a sketch how you would connect up an energy meter, such as the Elihu Thomson meter, on a 2-wire circuit. [Prel. 1897.]

15. Classify the meters described in this chapter under the two heads:—*Quantity meters, Energy meters*, and give your reason in each case.

16. Why must every kind of motor meter have some sort of braking device?

17. Make a list of the motor meters mentioned herein, and describe briefly the motive action and braking device employed in each case. Illustrate the same with simple sketches.

18. In what respects do the Hookham and Ferranti direct-current meters somewhat resemble each other?

19. Contrast the action of the Hookham alternating-current meter with that of the Shallenberger meter.

20. Distinguish between the Shallenberger and the Westinghouse meters as regards the way in which the rotating magnetic field is set up.

21. The Aron meter may be described as a continuous integrating one, whereas the Johnson and Phillips meter is an intermittent integrating instrument. Explain what is meant by this.

22. Give your own reasons for the necessity of periodically reversing the current in the pendulums of the Aron meter.

23. Give diagrammatic sketches similar to Figs. 134 or 159 showing the connections of the following meters to the supply mains—Schattner, Shallenberger, Hookham Direct-Current, Hookham Alternating, and Johnson and Phillips.

24. What would be the essential parts of an hour meter, and why must such necessarily belong to the clock type?

25. Suppose in a district where a two-rate system of charging was employed, the night and day prices were respectively 6*d.* and 2*d.* What different rates would you give to a two-rate meter, and how would you charge for the units indicated by the meter dials?

26. Explain the different kinds and the use of battery meters.

27. Expatiate in your own words on the principles and advantages of the maximum-demand system of charging for electricity supply. Mention any disadvantages you can think of.

*28. What is a maximum-demand indicator, and for what purpose is it employed? Why is such sometimes termed a rebate indicator?

29. Try to sketch out a demand indicator differing from the Wright and the Atkinson-Schattner instruments.

*30. A shop is supplied with electric energy on the 3-wire system through an energy meter of the motor type; show how the meter should be connected to the mains. [Prel. 1903.]

31. What are the essential features of a good house meter? Describe the Thomson energy meter, and show that the number of revolutions is proportional to the energy used. Why is it incorrect to call this instrument a "recording wattmeter"? [Ord. 1903.]

CHAPTER XIV.

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.); and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

*100. ELECTRIC MOTORS.—An *electric motor*, or *electro-motor*, or, as it is generally simply called, a *motor*, is a machine by which the energy of the electric current is converted into mechanical energy with the production of motion. It is thus the opposite of a dynamo, which converts mechanical into electrical energy. In other words, a dynamo gives current when motive power is applied to it, whereas a motor gives motive power when a current is passed through it. Like dynamos, motors may be divided into two great classes, (*a*) *direct-current motors*, and (*b*) *alternating-current motors*, i.e. motors designed to work with direct and alternating currents respectively.

Like dynamos also, direct-current motors may be either 2-pole, 4-pole, or multipolar; and may have either ring, drum, or disk armatures. As regards the excitation of their field magnets, this may be either series, shunt, compound, or separate (Chap. *VIII.*). In fact, the difference between dynamos and motors of the same class is so small, that, as a general rule, any given machine may be used either as one or the other. Separately-excited motors are, by the way, so rarely employed, that they need not be considered.

*101. SHUTTLE-ARMATURE MOTOR. — The simplest classes of direct-current motor such as are used in toy models, depend for their action upon the attraction and

repulsion set up between fixed and movable magnetic poles. This is the principle of the shuttle- or simple drum-armature dynamo when used as a motor.

The general construction of this motor is identical with that of the simple hand dynamo described in Chap. *VIII.* The commutator and brushes are so arranged, that when the armature is in the position indicated in Fig. 171, I., the commutator-segments *c, c,* and brushes *B, B,* shall just have come into contact, and given the armature polarity as shown. Repulsion consequently takes place between *N* and *a*, and between *S* and *b*; and attraction between *S* and *a*, and *N* and *b*; and the armature will revolve in the direction indicated by the arrow. This continues until the armature reaches the position shown in Fig. 171, II. At this point the brushes pass from the commutator segments on to the insulating portions *I, I,* between them; and no current flows round the armature. Its momentum, however, carries it round to the position shown in Fig. 171, III, at which instant the brushes again make contact with the segments; but not with the same ones as at first; so that the polarity of the armature is reversed, the end *a* being south, and the end *b* north. Repulsion now takes place between *S* and *a*, and between *N* and *b*, while attraction is set up between *N* and *a* and between *S* and *b*, and the armature continues its movement in the same direction as before. The state of things shown in Fig. 171, III., continues until the armature reaches the position indicated in Fig. 171, IV., when the current is cut off until the armature again reaches its first position (Fig. 171, I.). Then the current flows through once more, but in the reverse direction. The current should be cut off before the arma-

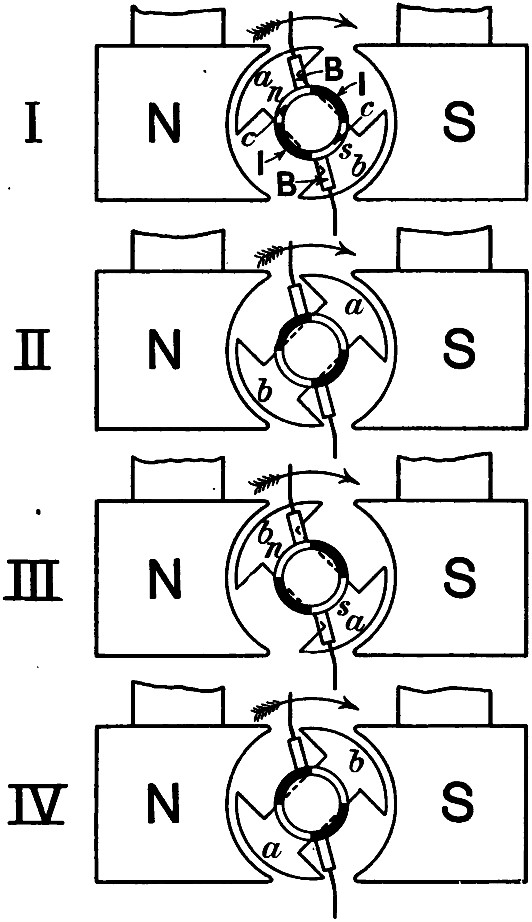


Fig. 171.—Principle of Shuttle-Armature Motor.

ture reaches the horizontal or "dead centre" position; and the reversal should take place after it has passed this position. To ensure this, the insulating pieces between the segments should be broader than in the case of a dynamo of this construction. Otherwise, in the first case, there will be a tendency to stop the rotation; and in the second case, a tendency to reverse the direction of rotation.

*102. MAGNETIC DRAG.—When a conductor carrying a direct current is placed in a magnetic field, at right angles with the lines of the latter, it will experience a force dragging or tending to drag it across the field, in a direction depending upon the direction of the current and of the field. This force is due to the interaction of the field set up by the current in the conductor and the field in which it is placed; and is proportional to the product of the strengths of the two fields.

The reason for the above action will be clear from Fig. 172, which represents, diagrammatically, the magnetic figure obtained with iron filings when a current-carrying conductor is placed in the field between a *N* and a *S* pole. The conductor is supposed to be passing vertically through the paper, and the current to be flowing upwards. If the conductor were removed to a distance from the magnet poles, its field would be indicated by concentric circles, and the + direction would be counter-clockwise (Chap. *III.*): while the field between the magnet-poles, away from the edges, would consist of straight lines passing from pole to pole, the + direction being from *N* to *S*. At the end of Chap. *IV.*, it was stated that the lines of adjacent fields will alter their shapes so as to run as far as possible side by side, and in the same direction; and further, that lines

running in the same direction repel one another, and that they tend to shorten themselves. Remembering this, it is fairly easy to account for the shape of the resultant field in Fig. 172, and the direction of the "magnetic drag" on the conductor. Supposing the conductor is placed in the field, and a current passed upwards through it, its field will be as shown by the small curved arrows. The direction of the magnet's field immediately below the conductor, as

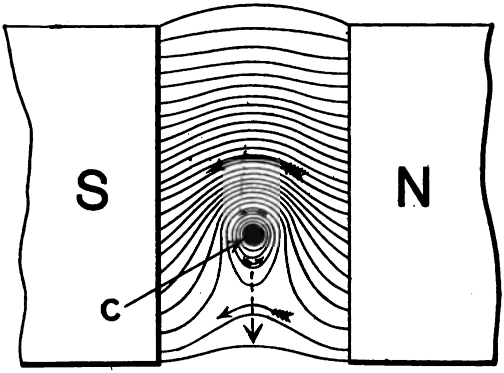


FIG. 172.—Magnetic Drag.

looked at in the sketch, will be in opposition to that of the bottom half of the field due to the current in the conductor. Some of the magnet's lines will consequently stretch so as to pass round the other side of the conductor, where they will be in the same direction as the lines due to the latter. This distortion will cause a crowding of the lines on the upper side of the conductor, and the field there will be increased in strength. Now the attraction between the lines of the

magnet's field and those set up by the conductor on its lower side; and the repulsion between the lines on the upper side of the conductor, will force the conductor downwards in the direction of the dotted arrow. This latter, therefore, indicates the direction of the *magnetic drag*, which, it will be noted, is at right angles with the permanent field. We may explain the effect in another way, by saying that the drag on the conductor is due to the effort of the permanent field to regain its normal shape, the lines tending to shorten themselves.

The reader should draw figures to prove to himself that the conductor would still tend to travel in the same direction if the direction of the current and the polarity of the field magnet were *both* reversed: and that it would tend to travel in the *opposite* direction if the current *alone* or the field *alone* were reversed.

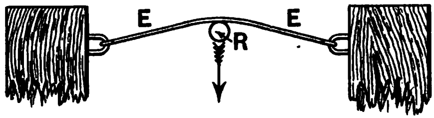


FIG. 173.—Analogy illustrating Magnetic Drag.

We may employ a mechanical analogy to illustrate the magnetic drag (Fig. 173). Here the distorted field of the magnet is represented by the stretched elastic band *E*, *E*, which, in its endeavour to assume its usual position, forces the vertical rod *R*, which represents the conductor, in the direction indicated by the arrow.

On this phenomenon of magnetic drag depends the action of all electric motors; for the armature, having current sent through, or (as in the case of most alternating-current motors (§ 135),) induced in its conductors,

and being placed in a magnetic field, is set in motion thereby.

103. MAGNETIC DRAG (*cont.*).—The magnetic drag or pull on a single straight current-carrying conductor, when placed at right angles with the lines of a magnetic field, may be calculated as follows :—

Let F be the force acting on the conductor, l the length of conductor in the field in cms., C the current (in amperes) flowing through the conductor, and $\mathbf{B}$ the flux density (Chap. *VI.*).

Then :— $$F \text{ (in dynes)} = \frac{C\,\mathbf{B}\,l}{10}$$

The divisor 10 is used to reduce the current to C.G.S. units (Chap. *VI.*).

As the gravitating force of a lb. is practically 445,000 dynes (Chap. *I.*), we may write :—

$$F \text{ (in lbs.)} = \frac{C\,\mathbf{B}\,l}{10 \times 445 \times 10^3} \text{ [1]}$$

EXAMPLE.—*A straight conductor, carrying a direct current of* 270 *amperes, lies at right angles to the magnetic flux of a field having an intensity of* 9000 *lines per sq. cm. Find the force* (*in lbs.*), *per foot of conductor, tending to pull it across the field.*

Here $C=270$, $\mathbf{B}=9000$, and $l=30{\cdot}5$ (taking one yard as equal to 91·44 cm.) [Chap. *I.*].

Thus :— $$F = \frac{270 \times 9000 \times 30{\cdot}5}{10 \times 445 \times 10^3}$$
$$= \frac{27 \times 9 \times 30{\cdot}5}{445}$$
$$= \frac{7411{\cdot}5}{445}$$
$$= 16{\cdot}5 \text{ lbs.}$$

[1] See footnote, p. 45.

*104. Principle of Drum-Armature Motors.—Practical motors, having ring or drum armatures, depend for their working upon the magnetic drag just described: and the action of the shuttle motor (§ 101), whose armature is virtually a simple form of the drum type, may be explained in this way.

Consider the simple coil shown in Fig. 174, and look

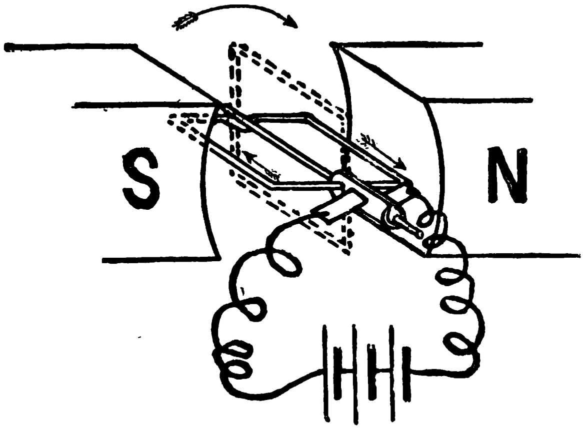


Fig. 174.—Principle of Drum-Armature Motors.

upon the two sides as separate current-carrying conductors. Bearing Fig. 172 in mind, a little consideration will show that the left-hand side of the coil will travel upwards, and the right-hand side downwards; the coil as a whole rotating in the direction shown by the curved arrow. When the coil reaches the upright dotted position, the commutator will reverse the direction of the current passing through it, and the coil will make a second half-revo-

lution; then the current will again be reversed, and so on. It should be noted that, with a single conductor (Fig. 172), the tendency is to force it across and out of the field; while in the present case the magnetic drag causes the rotation of the armature upon its spindle.

The motion of a simple coil, such as is shown in the figure, is not very regular; for the force acting on it is greatest when it is in the horizontal position, and nothing at all when it is in the vertical or dotted position. If two coils be employed (Fig. 175), one at right angles with the

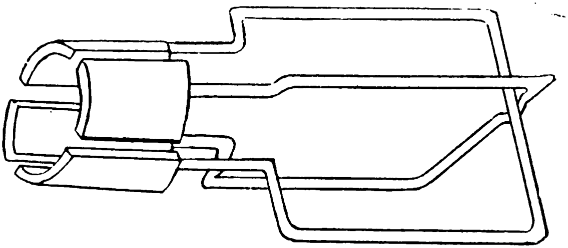


FIG. 175.—Two-coil Armature.

other, a more uniform motion results, since as soon as one coil leaves the best position, the other enters it. In this case a 4-part commutator must be used. By winding many coils on an iron core, and connecting them to a commutator, as is done in practical machines, a much greater and very uniform pull is exerted on the armature. As in a dynamo, the principal object of the iron core of the armature is to concentrate and strengthen the magnetic field (Chap. *VIII.*).

*105. RIGHT-HAND RULE FOR FINDING THE DIRECTION OF MOTION OF A CURRENT-CARRYING CONDUCTOR WHEN

PLACED IN A MAGNETIC FIELD; *e.g.* IN THE CASE OF A MOTOR ARMATURE (Maycock) (Fig. 176).[1]—As the direction of the magnetic drag on a current-carrying conductor depends upon both the direction of the current, and of the field in which the conductor is placed (§ 102), an easily-

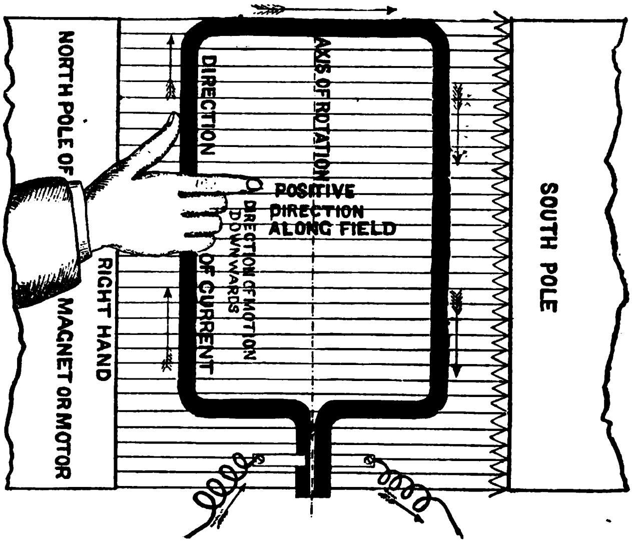


FIG. 176.—Motion of a Current-carrying Conductor.

remembered rule is handy. Such a rule is as follows:—*Place the right hand with the palm facing the conductor, and the thumb, forefinger, and the other fingers grouped stretched out at right angles with one another. The forefinger must point in the positive direction along the field, and the thumb in the direction of the current; then the other fingers will*

[1] See footnote, p. 63, Vol. I (5th Ed.).

denote the direction in which the current-carrying conductor will move.

The reader should apply this rule to verify the various cases given in §§ 102 and 104.

*106. PRINCIPLE OF RING- AND DRUM-ARMATURE MOTORS.—The action of ring-armature motors may be explained in two ways:—either by looking on the armature

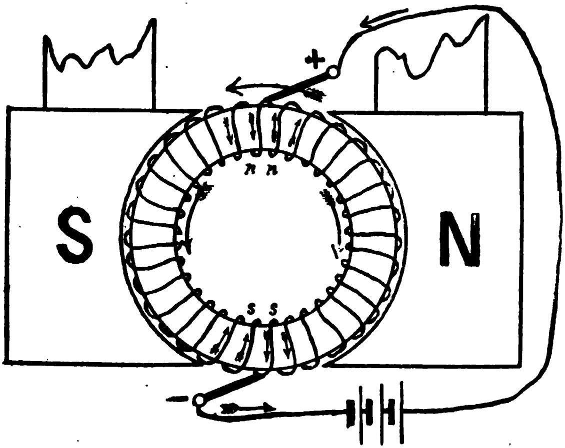


FIG. 177.—Principle of Ring-Armature Motors.

as a magnet, and thinking of the attractions and repulsions set up between its poles and the field poles; or by considering the magnetic drag on the conductors on the sides of the armature facing the field poles. The latter method is the better way of regarding the matter; but the former, though affording only an incomplete explanation, is very useful. We shall take them in the order given.

When the current enters the commutator of an ordinary ring armature, it divides, one part passing round one half and the other round the other half, both parts re-uniting at the negative brush. This will be understood from Fig. 177, where the commutator is omitted for the sake of clearness, and the distortion of the field (§ 116) is not taken into account. The two halves of the armature may be looked upon as semicircular electro-magnets, with their like poles brought together at the points where the current enters and leaves the ring, consequent *N* and *S* poles being formed continuously at those points as the armature rotates. The commutator and brushes are so arranged that these poles are on a diameter at right angles, or nearly so, with a line passing through the poles of the F.M. These latter consequently act on the poles of the armature, and the latter is continuously rotated in the direction shown by the arrow.

Fig. 178, which assists us with the other explanation, is virtually a repetition of Fig. 177, but sections only of the outer portions of the turns of the armature conductors are shown. Now in the conductors on the right-hand side the current is flowing inwards, while in those on the other side it is flowing outwards; as indicated by the signs $-\ -\ -$, $+\ +\ +$. The conductors on the right-hand side will therefore tend to move upwards across the field, and those on the other side downwards, and the armature will revolve in the direction shown by the curved arrow. As each conductor, or set of conductors, passes the commutating point, *i. e.* as the commutator segment in connection therewith passes under the brush, the current will be reversed in that particular conductor or set of conductors. In this figure, as

in the preceding one, the commutator is omitted for the sake of clearness.

Fig. 178 may also be taken to apply to a 2-pole drum armature, *i. e.* one for use in a 2-pole field: for, in spite of the apparent complications of drum winding (Chaps. *VIII.* and *IX.*), it will be found that the currents flowing in the conductors facing one pole of the field are all in one direction, while those in the conductors facing the other pole are all in the opposite direction.

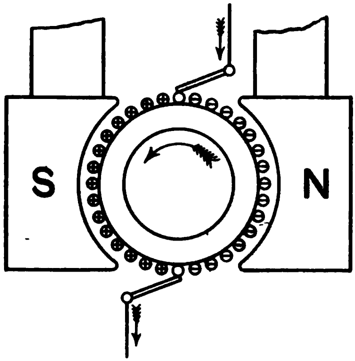


FIG. 178.—Action of Ring- and Drum-Armature Motors.

107. MOTOR-ARMATURE CORES.—Because of the sudden and heavy strains to which motor armatures are subjected, the use of slotted or toothed cores is a necessity, except in very small machines. In some motors, *tunnel* armatures are employed, the core disks of these having holes stamped round their edges, the conductors being threaded through the holes. In a dynamo, the armature core "drives" the conductors (Chap. *VIII.*); but in a motor, the conductors may be said to drive the core; though, as a matter of fact, most of the pull is exerted magnetically on the core teeth. In each case the chief object is to obtain a rigid and mechanically good fixing of the windings to the armature. The rigid fixing of the core to the shaft is another all-important point.

Fig. 179 shows three types of core disk, with the slots, etc., somewhat exaggerated in relative size in order that their shape may be clearly seen. *A* is an ordinary slotted core plate, *C* a tunnelled plate, and *B* a type half tunnel, half slot. Figs. 232, 240, and 245 show actual forms of core disk for both the stationary and rotating parts of motors.

108. DIRECTION OF ROTATION.—If the F.M. of a motor be separately excited, the direction of rotation of its armature may be reversed by reversing the current through it, or by reversing the polarity of the F.M. (§ 102). If a motor be series- or shunt-wound, then in either case,

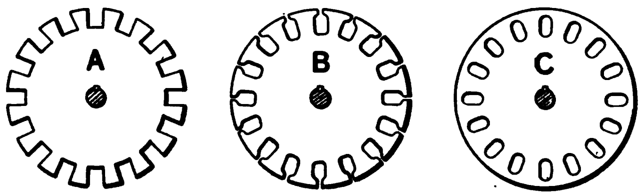


FIG. 179.—Core Disks.

if the driving current be reversed, both the polarity of the armature and of the F.M. will be changed; with the result that the armature will revolve in the same direction as before. This will be clear from a study of Figs. 180 and 181. To change the direction of rotation of the armature of a series- or shunt-wound motor therefore, either the current in the armature, or that in the F.M. windings, must be reversed; but not both.

When a motor is required to run in either direction at will, as is the case with all motors used for traction purposes—trains, trams, road vehicles, boats, etc.—the reversing gear is usually so arranged that the current in the F.M.

windings is always in the same direction, that in the armature alone being reversed. The latter may be accomplished by placing a reversing switch in the armature circuit.

There are various other methods of reversing motors, but none are so much used as that just described (§ 124).

The brushes used in motors (except very small ones)

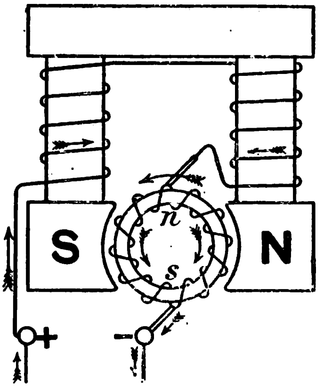


Fig. 180.—Series Motor.

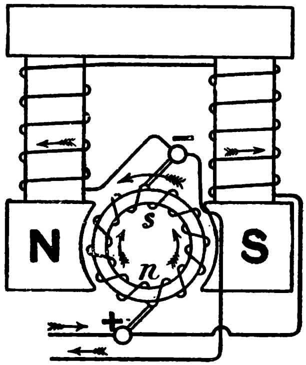


Fig. 181.—Shunt Motor.

are almost invariably of carbon, and are set end-on to the commutator so as to allow of the latter rotating in either direction. Some forms of brushes and holders suitable for motor work are illustrated in Chap. *VIII.*

A series machine, when used as a motor, turns in an *opposite* direction to that in which it would have to be turned if run as a dynamo, presuming the connections

were left untouched, and the polarity of the F.M. was to be the same in either case. This will be understood from a reference to Fig. 180, and an application of the left-hand rule (Chap. *IV.*), to find in which direction a current would be developed in the armature.

With a shunt machine the case is different. The armature will turn in the *same* direction when used as a motor as it would have to be turned if run as a dynamo, the polarity of the F.M. being the same in both cases. The student should refer to Fig. 181, and verify this statement for himself in the same way as in the case of a series machine.

A compound-wound machine (§ 118) will turn in the *same* direction as a motor as it would have to be turned if used as a dynamo, the polarity of the F.M. remaining the same.

109. TORQUE.—*Torque* is that which produces, or tends to produce, rotation of a body about its axis; and may be roughly described as *turning force.* Thus a certain amount of torque has to be applied to the handle of a screwdriver in driving a screw; while a very great deal is necessary at the shaft of a propeller to enable it to drive a ship through the water. The reaction between the current in a motor armature, and the magnetic field in which it is placed, gives rise to a torque on the armature shaft. In each of the above cases, the actual amount of power given out is proportional to the torque multiplied by the speed of rotation.

The calculation of the torque T on a motor armature is a fairly simple matter, for :—

$$T \propto C \mathbf{F} N$$

Here C is the total current[1] flowing into the armature, F the flux or total flow of lines, and N the number of conductors in series (§ 20). The torque T is obtained by dividing the product $C \mathsf{F} N$ by some quantity, according to the units in which T is to be expressed: thus to find T in pound-feet[2] the equation becomes:—

$$T \text{ (pound-feet) } = \frac{C \mathsf{F} N}{852 \cdot 3 \times 10^6}$$

C being expressed in amperes.

The torque on an armature is sometimes referred to as the "tangential pull on the armature."

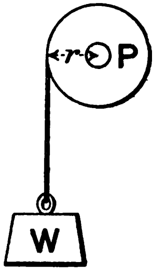


Fig. 182.—Torque.

Example.—*A 2-pole motor armature, wound with* 170 *external conductors, is placed in a field whose total flux is* 7,000,000 *lines. What is the torque, or tangential pull on the armature, when a current of* 150 *amperes is sent through it?*

---

1 The current C' flowing through any one conductor in a 2-pole armature is half the *total* current C passing through the armature, the two halves of the latter being in parallel (§ 106).

2 *Units of Torque.*—It will be remembered that the centimetre-dyne (or erg), foot-lb., etc., are units of work (Chap. *I.*). If these terms are reversed—as dyne-centimetre, pound-foot—they may be employed to denote units of *torque*, or what may otherwise be defined as *turning force.* A *dyne-centimetre* in this sense means a torque produced by a force of one dyne acting at a radius of one cm. Similarly a *pound-foot* signifies the torque produced by the force of one lb. acting at a radius of one ft. To illustrate this, in Fig. 182, P is a pulley around which passes a cord, with a weight W at the end of it, the other end of the cord being wound round and attached to the pulley. Clearly the torque on the pulley depends both on W (which may be expressed in dynes, lbs., etc.), and on the radius r, i. e. $T = Wr$.

Here $C=150$, $\mathsf{F}=7\times10^6$, and $N=170$.

Then :—T (in pound-feet) $=\dfrac{150\times7\times10^6\times170}{852{\cdot}3\times10^6}$

$=209.$

110. TORQUE, SPEED, AND POWER.—It was mentioned at the beginning of the preceding paragraph, that the power given out by a rotating body, such as a shaft, pulley, etc., was proportional to the product of its torque and speed.

If T = torque in pound-feet, and n = revolutions per second :—

$$\text{Power (in foot-pounds per sec.)}=2\pi nT,$$

and :—

$$\text{Power (in foot-pounds per min.)}=2\pi nT\times60.$$

Thus :— $$\text{H.P.}=\frac{2\pi nT\times60}{33{,}000}=\cdot0114nT.$$

EXAMPLE.—*The torque on a motor pulley is* 900 *pound-feet, and its speed is* 1000 *rev. per min.: what power is its shaft transmitting?*

Here :— $n=\dfrac{1000}{60}=16{\cdot}67$, and $T=900$.

Then :— $\text{H.P.}=\cdot0114\times16{\cdot}67\times900.$

$=171.$

*111. COUNTER E.M.F. OF A MOTOR.—When the armature of a motor is revolving in the field, its conductors cut lines of force; and as a consequence, E.M.F. is generated in them, just as if the machine were being used as a dynamo. This E.M.F. opposes the applied working pressure and current of the motor, as the student can easily prove for himself by referring to Figs. 180 and 181, and applying the left-hand rule (Chap. *IV.*). It is consequently spoken of as the *counter* or *back E.M.F. of a motor*, and is obviously

greater the faster the motor rotates. On this account, when a motor is supplied at a constant pressure, the more rapid its rotation, the smaller is the current flowing through it, and the less the power transmitted, for the greater is the opposing E.M.F.

As was shown at the end of the preceding paragraph, the power given out by a motor is proportional to the product of its torque and speed. Now, with a given armature and field, the torque depends on the current in the armature, and this current in its turn depends on the difference between the working pressure and back E.M.F. Thus, if E is the working pressure, E the back E.M.F., and R the resistance of the armature circuit,[1] the current C in the armature will be :—

$$C = \frac{E - \mathsf{E}}{R}$$

When a motor is required to develop a certain power at a given speed, that is to say, when it is required to give a certain torque (*i. e.* to have a certain current in the armature) at that speed; it is necessary to find what the back E.M.F. will be at the speed given, and arrange the working pressure to satisfy the above equation.

The counter E.M.F. E of a motor may be calculated exactly as is the generated E.M.F. in the case of a dynamo (§§ 20 and 21).

$$\text{Thus :—}\mathsf{E}\ (\text{in volts}) = \frac{N\,\mathbf{\mathsf{F}}\,n\,p}{10^8}$$

Here N is the number of conductors in series on the

[1] In a series motor, R = resistance of armature + resistance of F.Ms. In a shunt motor, R = resistance of armature only.

armature, F the total flux, n the number of revolutions per second, and p the number of pairs of poles.

$p = 1$, 2, or 3, etc., according as the machine has 2, 4, 6 or more poles.

EXAMPLE.—*A bipolar series motor is required to develop* 30 *H.P. at a speed of* 600 *revs. per min. The combined resistance of its armature and field coils is* 1·3 ω. *The flux of the field is* 24 × 10⁶ *lines, and the armature carries* 400 *active conductors. What pressure must be applied to its terminals, what will be the input in kilowatts, and what will be the efficiency?*

The problem is to find:—(i.) the torque; from this (ii.) the current; then (iii.) the back E.M.F.; (iv.) the working pressure; and lastly (v.) the commercial efficiency and input.

(i.)
$$\text{H.P} = \cdot 0114 nT$$
$$i.e.\ T = \frac{\text{H.P.}}{\cdot 0114 n}$$

In the present case:—
$$T = \frac{30 \times 60}{\cdot 0114 \times 600}$$
$$= 263 \text{ pound-feet.}$$

(ii.)
$$T = \frac{C\mathsf{F}N}{852{\cdot}3 \times 10^6}$$
$$i.e.\ C = \frac{T \times 852{\cdot}3 \times 10^6}{\mathsf{F}N}$$

In the present case:—
$$C = \frac{263 \times 852{\cdot}3 \times 10^6}{24 \times 10^6 \times 400}$$
$$= \frac{262{\cdot}6 \times 852{\cdot}3}{9600}$$
$$= 23{\cdot}3 \text{ amperes.}$$

(iii.)
$$E \text{ (volts)} = \frac{N\mathsf{F}np}{10^8}$$

In the present case:—
$$E = \frac{400 \times 24 \times 10^6 \times 10}{10^8}$$

$$= 40 \times 24$$
$$= 960 \text{ volts.}$$

(iv.)
$$C = \frac{E - \mathsf{E}}{R}$$
$$i.e.\ E - \mathsf{E} = RC.$$

In the present case :— $C = 23{\cdot}3$ amperes, and $\mathsf{E} = 960$ volts.

$$\text{Thus :—} E - 960 = 1{\cdot}3 \times 23{\cdot}3$$
$$i.e.\ E = 30 + 960$$
$$= 990 \text{ volts.}$$

(v.) As will be shown in § 113:—

$$\text{Commercial efficiency} = \frac{\text{Output}}{\text{Input}}.$$

In the case under notice the output is 30 H.P., and the input :—

$$\left(\frac{E \times C}{746}\right) = \frac{990 \times 23{\cdot}3}{746}$$
$$= 30{\cdot}9 \text{ H.P.}$$

$$\text{Thus the efficiency is } \frac{30}{30{\cdot}9} \times 100 = 97\%.$$

This figure is unduly high, as, in order to simplify the example, no allowance has been made for eddy current, frictional, and other losses.

*112. Power absorbed by a Motor.—*The power absorbed by a motor is approximately proportional to its load.* The faster a given motor, supplied at a given pressure, rotates, the less work it does; and the less will be the power absorbed, for the greater will be the counter E.M.F. The more slowly the motor rotates, *i. e.* the heavier the work it has to do, the greater the power absorbed, as the counter E.M.F. will be diminished.

Owing to the absorption of power being practically in proportion to the demand, electric motors possess great advantages over other kinds of motor, such as steam-, gas-, or oil-engines, etc. A train or tram motor, for instance, on first starting, takes a large current, and is thus able to

exert the great effort required at starting. As the speed increases the counter E.M.F. rises; and the current, and therefore also the power developed, decrease. When the motor is running at full speed, it takes its minimum current and power.

The electrical power absorbed by a direct-current motor is given by the product of the current passing through it and the pressure at its terminals.

EXAMPLE.—*A motor connected to mains kept at a constant pressure of* 250 *volts, takes a current of* 75 *amperes. What is the power delivered to it?*

$$\begin{aligned} \text{Power} &= E \times C \text{ (Chap. } II.) \\ &= 250 \times 75 \\ &= 18{,}750 \text{ watts} \\ &= \frac{18{,}750}{746} = 25 \text{ H.P.} \end{aligned}$$

113. EFFICIENCY OF MOTORS.—The *commercial or total efficiency* of a motor is the ratio of the mechanical power given out by it to the electrical power delivered to it. Thus:— percentage commercial efficiency =

$$\frac{\text{Mechanical power given out} \times 100}{\text{Electrical power delivered.}}$$

EXAMPLE.—*A motor is required to give out* 8 *H.P. when used on mains at* 110 *volts. Assuming that its commercial efficiency will be* 88%, *what current must it take?*

Let x = electrical power delivered. Then :—

H.P. given out : H.P. put in :: 88 : 100

i. e. :— 8 : x :: 88 : 100

$$\begin{aligned} x &= \frac{100 \times 8}{88} \\ &= 9{\cdot}1 \text{ H.P. (Power to be delivered.)} \end{aligned}$$

$$\begin{aligned} \text{The current therefore} &= \frac{9{\cdot}1 \times 746 \text{ (watts)}}{110 \text{ (volts)}} \\ &= 62 \text{ amperes.} \end{aligned}$$

114. Electrical Efficiency.—When a motor first starts, the current passing through it is comparatively large; but as it gets up speed, its counter E.M.F. increases and so cuts the current down. When the motor is at rest, and current is turned on, it is obviously doing no work; as no power is being utilized, though the current through it is at a maximum. Directly the motor begins to turn it commences to do work; and the faster it runs, the greater becomes its back E.M.F., and the greater is the *proportion of power utilized.* It must be noted that, while, as we have seen, the torque is greatest when a motor is running very slowly, and decreases as the speed increases; the power given out increases just at first, and then decreases as the speed rises, and the proportion of the power utilized increases. The ratio or proportion of the electrical power utilized to that given to the motor, is a measure of its *electrical efficiency.*

Thus :— percentage electrical efficiency =

$$\frac{\text{Electrical power utilized or turned into motive power} \times 100}{\text{Electrical power supplied.}}$$

From the foregoing it should be clear that the electrical power utilized = $\mathsf{E}C$, and that the power supplied is EC (or $EC + ECs$ in the case of shunt or compound motors, where Cs is the current in the shunt winding).

$$\therefore \text{ percentage electrical efficiency} = \frac{\mathsf{E}C \times 100}{EC}$$

$$\frac{\mathsf{E} \times 100}{E}$$

$$\text{or electrical efficiency} = \frac{\mathsf{E}}{E}$$

Here E, as before, stands for the back E.M.F. developed

by the motor, and E for the working pressure applied to it. Thus the *electrical efficiency* of a series and also (approximately) of a shunt motor is the ratio of its back E.M.F. to the working E.M.F.; and it consequently varies at different speeds, being nothing when the motor is at rest, and increasing as the speed and the back E.M.F. rise.

The losses in a motor may be set down under five heads, thus:—

(i.) Friction of bearings, gearing, and brushes.

(ii.) Air friction.

(iii.) Hysteresis.

(iv.) Eddy currents.

(v.) C^2R loss in armature and field conductors.

The first four of these account for what is termed the *stray power* in a motor.

The *mechanical* and the *commercial* or *total efficiencies* of a motor, and their relations to the electrical efficiency, are as follows:—

EFFICIENCY.

$$\text{Electrical} = \frac{\text{Electrical power converted into Mechanical power.}}{\text{Electrical power absorbed.}} \left\{ \begin{array}{l}\text{Efficiency of the}\\ \text{electrical device.}\end{array}\right.$$

$$\text{Mechanical} = \frac{\text{Mechanical power available for useful work.}}{\text{Electrical power converted into Mechanical power.}} \left\{ \begin{array}{l}\text{Efficiency of the}\\ \text{mechanical parts.}\end{array}\right.$$

$$\left.\begin{array}{r}\text{Commercial}\\ \text{or Total}\end{array}\right\} = \frac{\text{Mechanical power available for useful work.}}{\text{Electrical power absorbed.}} \left\{ \begin{array}{l}\text{Efficiency of}\\ \text{conversion.}\end{array}\right.$$

$$\text{Electrical Efficiency} \times \text{Mechanical Efficiency} = \left\{ \begin{array}{l}\text{ommercial}\\ \text{Efficiency.}\end{array}\right.$$

Since $\frac{\text{Elec. P. converted}}{\text{Elec. P. absorbed}} \times \frac{\text{Mech. P. available}}{\text{Elec. P. converted}} = \frac{\text{Mech. P. available.}}{\text{Elec. P. absorbed.}}$

The difference between the electrical and commercial efficiencies of a motor is most marked when it is fitted with self-contained speed-reducing gear, and the mechanical power given out is measured at the slow shaft of this gear and not at the armature shaft. When the power of a motor is taken directly off the armature shaft, the difference between the two efficiencies is a minimum.

115. To Calculate the Efficiency of a Dynamo when used as a Motor.—Knowing the output of a dynamo at a given speed, and its resistance; to find its electrical efficiency as a motor.

Example.—*A series dynamo has an armature resistance of* ·6 ω, *and a field resistance of* ·6 ω; *and at a certain speed it gives a current of* 12 *amperes at* 115 *terminal volts. Find its electrical efficiency as a motor at that speed and current.*

The problem is:—(i.) To find the E.M.F. of the dynamo, which will, of course, be equivalent to the back E.M.F. of the machine when used as a motor at that speed and current: (ii.) knowing the back E.M.F. and the resistance of the machine, to find the necessary working pressure to force a current of 12 amperes through the motor: and, (iii.) knowing the watts supplied to and those lost in the machine, to deduce therefrom its electrical efficiency as a motor.

(i.) The total resistance of the machine is 1·2 ω,[1] and the loss of volts in it is $12 \times 1{\cdot}2 = 14{\cdot}4$ volts. The total volts generated by the dynamo consequently $= 115 + 14{\cdot}4 = 129{\cdot}4$ volts. The back E.M.F. E of the machine, when

[1] See footnote, p. 323.

used as a motor at the given speed, will therefore be 129·4 volts.

(ii.) The necessary pressure E to force a current C through a known resistance R, against a back E.M.F. $\mathcal{E}$ is:—

$$E = (C \times R) + \mathcal{E}.$$

In this case:—

$$\begin{aligned} E &= (12 \times 1{\cdot}2) + 129{\cdot}4 \\ &= 14{\cdot}4 + 129{\cdot}4 \\ &= 143{\cdot}8 \text{ volts.} \end{aligned}$$

(iii.) The watts supplied to the machine = 143·8 × 12 = 1725·6 = say, 1726 watts.

$$\begin{aligned} \text{The watts lost in machine} &= C^2R \text{ (Chap. IV.).} \\ &= 12^2 \times 1{\cdot}2 \\ &= 144 \times 1{\cdot}2 \\ &= 172{\cdot}8, \text{ say } 173 \text{ watts.} \end{aligned}$$

∴ watts available as motive power = 1726 − 173 = 1553, making no allowances for other losses in the machine.

$$\begin{aligned} \therefore \text{ electrical efficiency} &= \frac{1553 \times 100}{1726} \\ &= 90\%. \end{aligned}$$

The above method is instructive, but of course the shortest way to find the electrical efficiency, knowing E and $\mathcal{E}$, is as follows:—

$$\begin{aligned} \text{Electrical efficiency} &= \frac{\mathcal{E} \times 100}{E} \text{ (§ 114)} \\ &= \frac{129{\cdot}4 \times 100}{143{\cdot}8} \\ &= 90\%. \end{aligned}$$

The reader should compare the two methods.

116. Lead of Dynamos and Motors.— In Chap. *VIII.* it was briefly explained that the field of a dynamo, and therefore also the neutral points on the commutator, are twisted round in the direction of rotation, thus necessitating the giving of a *forward lead* to the brushes. That is to say, the latter have also to be moved round slightly, in the direction of rotation, from their theoretical positions.

In a motor, the field is likewise twisted or distorted, but in the *opposite* direction to that of the rotation. It is consequently necessary to give the brushes a *backward lead* or a *lag.*

The reasons for the above may be roughly understood from the following figures, dealing with 2-pole fields only; though, be it remembered, the lead of a dynamo is forward, and of a motor backward, whatever the number of field poles.[1]

Fig. 183, I., represents the flux through, and the consequent polarity (dotted N.S.) of the armature core of a dynamo or motor when stationary, and when no current is flowing through the armature. The diameter of commutation (Chap. *VIII.*) would then be as shown by the vertical dotted line *D.* Now suppose (Fig. 183, II.) the armature is driven as a dynamo in the direction of the curved arrow. The current flowing in the two halves of the armature will then be such as magnetize the top and bottom of the core as shown, neglecting for the moment the magnetization of the core by the field.

[1] Some machines are constructed with a view of reducing or altogether doing away with the necessity for lead or lag, but such cannot be considered here.

In Fig. 183, III., the joint effect of the magnetizations of the core due to (i.) the flux of the field, and (ii.) the flow of current in the armature, is shown; the consequent twist of the field being approximately as drawn in Fig. *178*. The dotted line *D* represents the new diameter of commutation, this being twisted round in the direction of rotation.

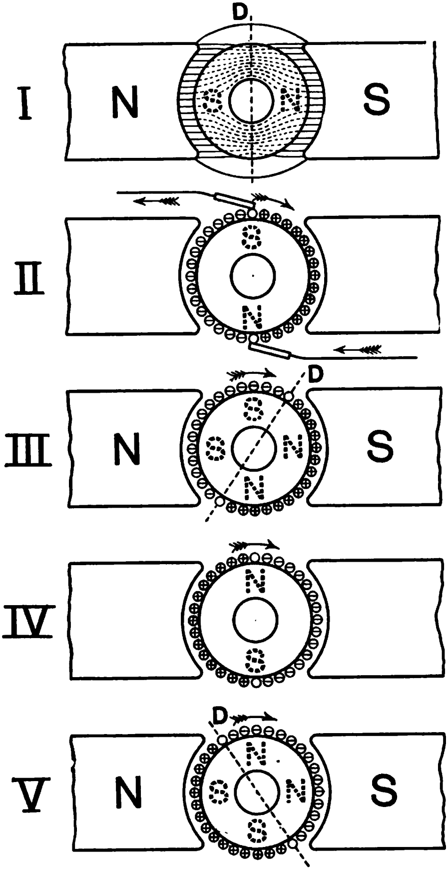


FIG. 183.—Lead and Lag of Brushes.

Now, if the polarity of the F.Ms. and the direction of rotation are to be the same as before; when the machine is used as a motor, the current must be sent in the opposite direction through the armature coils (§ 108). The polarity of

the core due to the current flowing through its coils will then be as shown in Fig. 183, IV. Thus the joint effect of the magnetizations of the core due to the current and to the field, will be as shown in Fig. 183, V.; and the dotted line or diameter of commutation *D*, being twisted in a backward direction from its theoretical or upright position (Fig. 183, I.), it follows that the lead of the brushes must also be backward.[1]

*117. Difference in Action between Series and Shunt Motors. Starting Switches.—The field magnets of motors may be either series-, shunt-, or compound-wound; or they may be separately excited, these terms having the same general meaning as when applied to dynamos (Chap. *VIII.*). The method adopted depends both upon the supply circuit from which the motor is to derive its current, and on the work for which it is intended; for what will succeed well under certain conditions may work very badly under others. Compound-wound motors possess certain advantages over those with plain series or shunt excitation under definite conditions; and such are briefly referred to in § 118. Separately-excited motors are so rarely employed, that it is not necessary for us to deal with them here.

The series motor is perhaps the most extensively used for heavy work, especially for traction purposes (§ 129),

[1] Some confusion is likely to arise as to the direction of the current indicated by the signs in the little circles in Figs. 178 and 183. In all cases, for the sake of uniformity, the + sign should denote that the current is flowing outwards, and the – sign that it is flowing inwards. This is also the way the signs would be used in the case of generators. In some motor diagrams that we have seen, however, the reverse is the case; the + sign denoting the inward flow of the current, and the – sign the outward flow.

where a very large torque is required at starting. From Fig. 184, which shows the connections of such a motor, it must be evident that, when the pressure is first applied, the back E.M.F. is a minimum, and a large current flows through both armature and field coils, the latter being excited to their greatest degree. In practice, a switch is used which inserts resistance in the circuit when the motor is started. Otherwise a very large current would pass, which would probably result in the dangerous heating of both armature and field-magnet windings, especially if the motor had to start against a heavy load.

There are many kinds of such *starting switch* (§ 119),

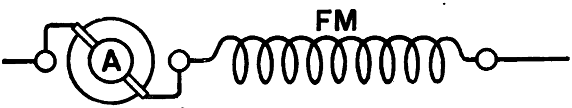


FIG. 184.—Circuit of Series Motor.

and a simple form is shown diagrammatically in Fig. 185. When the lever *L* is in the position shown, no current passes through the motor. When *L* is placed on the second contact, the current is put on, but through the whole of the resistance. As the motor gets up speed, the lever may be successively moved over the stops to the last contact *C*, when the full pressure will be applied to the motor, the mains from which the supply is taken being supposed to be kept at a constant P.D. The speed of a series motor may be altered by varying the pressure at its terminals; and this is another feature which makes it so useful in traction work; the alteration of pressure being effected, for instance, by the use of a variable resistance

in circuit. With such a motor, the speed is proportional to the pressure, and the torque to the current.

Series motors are not adapted for stationary work where the load varies considerably, as in the driving of the shafting or machinery in a factory, where machines are constantly being thrown on and off by means of fast and loose pulleys. The reason for this is that if the load is suddenly taken off the motor while the pressure is kept on its terminals, it will instantly begin to "race" or run at a

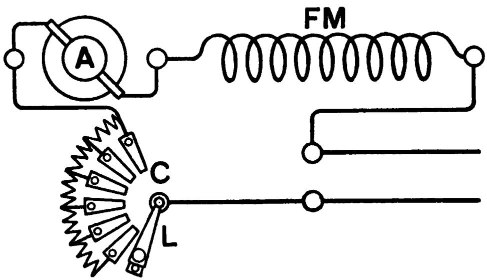


FIG. 185.—Simple Starting Switch for Series Motor.

high rate of speed. Series motors are, however, suitable for driving fans, pumps, and other machines with a constant load.

Shunt motors differ very materially in their action from series motors, because of the difference in the connection of the field coils to the circuit (Fig. 186). Unlike the series motor, with a steady pressure, the excitation of the fields will always be the same, the current in the armature alone altering. The latter will tend to run at a fairly uniform speed at varying loads. Thus if the load be increased, the speed, and therefore also the counter E.M.F., momentarily

fall off, and a stronger current passes through the armature, enabling it to exert a greater torque. Conversely, if the load decreases, the counter E.M.F. will increase, and this will decrease the armature current, and consequently the torque also. Thus the speed will remain fairly constant. Though shunt motors are not, like series motors, adapted for starting against a heavy load, owing to the excitation being constant; they are very suitable for ordinary motive purposes, such as driving stationary machines of various kinds.

The starting switches for shunt motors differ from those used with series motors. The current must first be sent through the field coils, and then through the armature with resistance in series, which latter may afterwards be gradually cut out. Such an arrangement is shown diagrammatically in Fig. 187. One end of both the armature and F.M. circuits is joined to one supply terminal $T-$; the other ends, as well as the resistances R, R', and R'', being connected, in the order shown, to the contact-tongues *1*, *2*, *3*, *4*, *5*, and *6*. C is a contact-piece pivoted at p, and capable of rotation, in the direction shown by the curved arrow, by means of the handle H. When it is moved far enough to connect together tongues *1* and *2*, the current passes through the F.M. coils. A further movement connects *1*, *2*, and *3*, and puts the current on to the armature

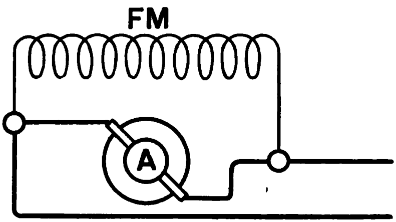


FIG. 186.—Circuit of Shunt Motor.

through the resistances R, R', and R''. The next step short-circuits R, the next both R and R', and the last R, R', and R'', so that there is then no extraneous resistance in the armature circuit. In practice, of course, it is necessary to have more than three resistance steps.

Practical forms of motor-starting switch are dealt with in §§ 119–124.

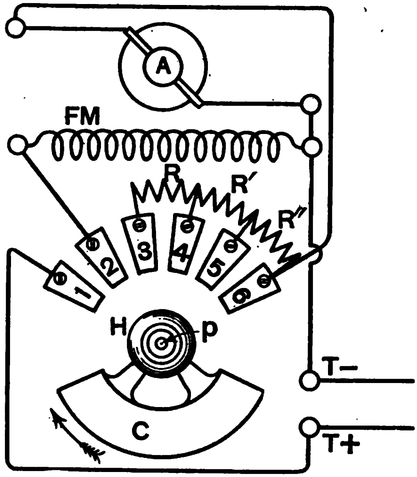


FIG. 187.—Simple Starting Switch for Shunt Motor.

The speed of a series or shunt motor, supplied from constant pressure mains, may be varied by altering its field excitation. It will run *faster* if the field excitation be weakened, and slower if it be strengthened: the load being kept constant. The reason of this is that, owing to the reduction of the field, the back E.M.F. decreases, and the latter is only restored (so as to keep the product $E\ C$ constant) by an increase of speed, which thereupon takes place; and *vice versâ* (§ 114).

The field excitation of motors may be governed in much the same ways as that of dynamos (§§ 11 and 12).

118. COMPOUND-WOUND MOTORS.—It was explained in § 8 that the effect of compound winding in dynamos is

to cause them to generate a constant E.M.F. when driven at a constant speed; even though the current taken out of the machine varies within wide limits. Conversely, if we wind a motor with both shunt and series coils, it will run at a constant speed when supplied at a constant pressure, even though the load varies considerably. But while in a dynamo the shunt and series coils help each other, or are *cumulative* in effect; a compound motor must be *differentially wound*, that is to say, the series coil must oppose or tend to lessen the effect of the shunt coil.

The reason for this is as follows:—Consider a simple shunt-wound machine (Fig. 186) supplied at a given constant pressure V, and running at a certain speed with a given load. If the load be considerably reduced, the current in the armature must decrease: but the current cannot decrease unless in some way the back E.M.F. of the armature be increased. The motor consequently runs at a higher rate of speed in order to bring about this increase in the back E.M.F. Now suppose the machine to be differentially compounded (Fig. 188), so that the effect of Se is to oppose that of Sh. Then, whenever a reduction of load takes place, the current flowing through the armature and Se will decrease, and the flux of the field will increase, thus enabling the machine to generate a proportionately greater counter E.M.F. without any increase in speed.

In a compound-wound dynamo the speed is kept constant, and the current in the armature and series winding varies with the load, the effect of the series winding being to *help* the shunt winding, and prevent the P.D. at the terminals from altering. In a compound differentially-wound motor, on the other hand, it is the working P.D.

which is kept constant. The current in the armature and series winding varies with the load, but the effect of the series winding is to *oppose* the shunt winding, and prevent the speed from altering.

Compound motors are most useful when frequent stoppages are necessary, and when the load varies suddenly. Where large starting torque is required, and constant speed is not important, the motor windings should be cumulative, not differential. Large starting torque may be obtained, without sacrificing constancy in speed, by arranging the switch gear and the windings so that the latter are cumulative on starting the motor; the series windings being differentially connected when the motor has attained its normal speed. Compound motors are not often used, however, as well-designed series and shunt machines will fulfil most conditions but that of absolutely constant speed, and the latter is not often indispensable.

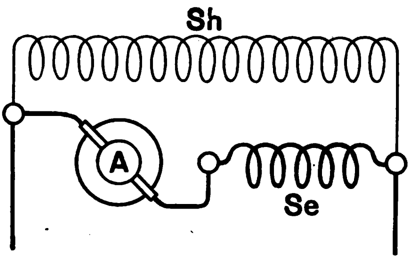


FIG. 188.—Circuit of Compound Motor.

As will be evident from Fig. 188, there is just a possibility of reversing the polarity of a differential compound motor, unless the usual care is taken to start up gradually. This difficulty may be avoided by so arranging the switch, that the series coil is either short-circuited, or its connection reversed, at the moment of starting.

An illustration of the adaptation of a compound-wound

dynamo to motor work is given in Example (*b*), § 127.

119. MOTOR-STARTING SWITCHES.—In the preceding paragraph, it was explained that a multiple-way switch, connected with a graduated resistance, must be used with motors; so that the current may be applied gradually to the latter on starting; and, when necessary, varied in strength during working. Practical forms of motor-starting switch have various devices for ensuring the protection of the motor from overheating; and in the more elaborate of these, it is impossible for the most careless attendant to do harm.

Referring to Fig. 185, it will be evident that if a simple multiple-way switch be used, there is nothing to prevent the operator from working the lever round quickly instead of gradually, and so practically putting the full pressure on to the motor before it has had time to start. In the best forms of motor-starting switch, sometimes termed *fool-proof* switches, it is rendered impossible for the switch lever to be moved over the stops otherwise than slowly.

A switch for use for starting purposes only is termed a *motor-starting switch* or *rheostat*, or *motor starter;* while a *motor controller* or *regulating rheostat* is a switch which enables the speed to be governed by altering the resistance in circuit; and a *reversing controller* enables also the direction of rotation to be altered at will. In a controller, the two functions of starting and controlling are combined in one switch. The graded resistances used with these switches are generally formed of wire, this being mounted and insulated in a variety of different ways, which cannot be considered here. It may be pointed out, however, that while

the resistance coils of a starter are only required to carry current during the very short time occupied by the motor in getting up speed; those of a "controller" or speed regulator have to carry current continuously, and must necessarily be of ample carrying capacity. All the best switches are now so arranged that the contact lever automatically returns to the "off" position should the supply pressure fall or fail, or the current become excessive.

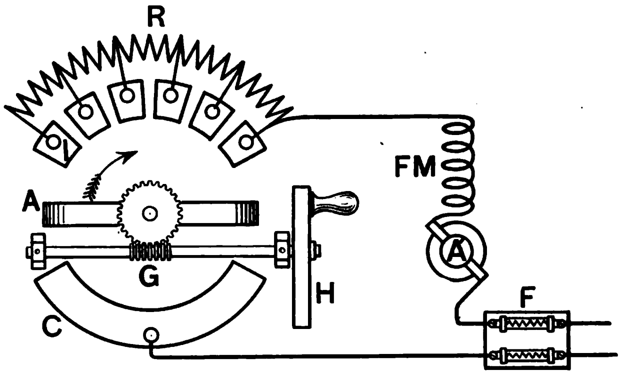


FIG. 189.—Simple Slow Starter and Controller for Series Motor.

102. STARTERS FOR SERIES MOTORS.—For a series-wound motor driving, say, a fan; the starter and controller would be combined in one, the connections of the circuit being as in Fig. 185. To prevent the resistance being cut out too quickly, some such arrangement as is given in Fig. 189 would be preferable. Here the movable switch-arm *A*, which is shown in the "off" position, is rotated in the direction of the curved arrow by the hand-wheel *H*, through worm or screw-gearing *G*, so that it cannot possibly be turned

too quickly. When *A* has been moved a short distance from the position illustrated, its right-hand end makes contact with the curved contact-plate *C*, and its left-hand end with the first of the resistance contacts *I*; and the current is thus put on to the motor through the whole of the resistance *R*. As *A* moves further round; the resistance is gradually cut out. The fuses *F* must be carefully adjusted

Fig. 190.—Simple Slow Starter and Controller for Series Motor (Moy).

to prevent too heavy a current passing through the motor from any unforeseen cause; and no other switch than that on the controller should be used, thus making it certain that all the resistance is in circuit every time the motor is started. An actual switch of this description is depicted in Fig. 190, the resistance coils being mounted in the frame behind. The upper part of this frame has been cut away in order to reduce the size of the figure.

When it is not necessary that any of the resistance should be in circuit after the series motor has started, some such switch as that diagrammed in Fig. 191 may be employed. A helical spring coiled round the arm axle *P*, and acting on the switch-arm *A*, tends to keep it in the "off" position against the stop *S*. This arm carries a soft iron armature *I*, which is held by the poles of the electro-magnet *E* when, in starting the motor, the arm has been gradually forced over as far as it will go. The coil of the magnet is connected up as shown, and should anything happen to interrupt the current, *A* will be released, and will fly over to the "off" position. *E* is usually shunted by a small resistance *R*, so that only a portion of the main current flows through it. This device is termed a *no-voltage release*, and ensures that all the resistance is in circuit every time the motor is started. With this type of starter it is usual to have a separate switch for breaking circuit, as indicated at *SW*; and it will be clear that when the motor is stopped by opening *SW*, *A* will be released. Further, it will be impossible to close the circuit at the starter until it has been first closed at

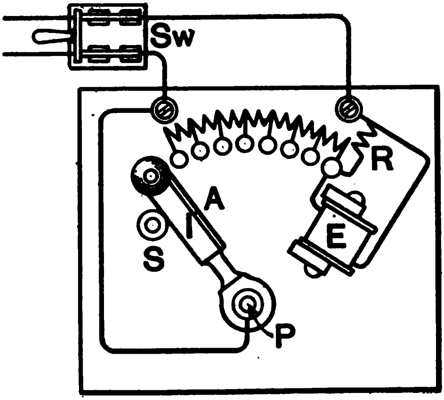


FIG. 191.—Starter for Series Motor.

Sw. It would be well to fix *Sw* out of arm's length of *A*, so that the operator could not hold *A* over with one hand, then close the circuit at *Sw*, and so defeat the purpose in view.

In Fig. 191A we have a diagram of a combined starter and regulator for a series motor, the actual appliance being shown in Fig. 191B. In the former figure, the armature lever *A* and the handle lever *H* are shown in an inter-

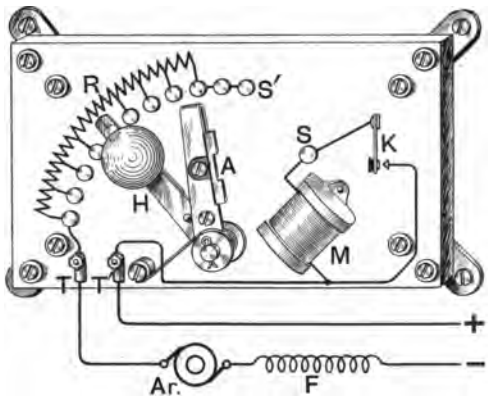


FIG. 191A.—Diagram of Series Motor Regulator (Veritys).

mediate position, as they would be in the act of putting the switch "on," or as if they were flying "off"; while in the latter the levers are in the "off" position. *A* and *H* are pivoted about the same axis, but *A* only is acted upon by the pull-off spring, which happens when the magnet *M* is too weak to hold *A* to itself. One of the supply mains (say the —) is connected through the field *F* and armature *Ar* of the motor to, say, the left-hand terminal

T, and the other main to the right-hand terminal *T′*. No current can flow until (by moving *H* to the right and forcing *A* round in front of it) the armature of *A* is brought against the poles of *M*, and the extremity of *A* makes contact with the stud *S*. Current then flows *viâ* *T′*, *M*, *S*, *A*, and *H* to the stud *S′*, and thence through the whole of the resistance *R* to the motor. *H* is then moved *backwards* to cut out the resistance, and may be left on any intermediate stop to regulate the speed of the motor.

Fig. 191B.—Series Motor Regulator (Veritys).

Should the pressure fall, or the supply fail, *M* will release *A*, and the latter will fly round to the off position, forcing *H* in front of it. To stop the motor the key *K* is depressed, thus short-circuiting *M*; and the same thing happens.

The apparatus illustrated has only a no-voltage release, but an *excess-current* or *overload release* is obtained by fitting another magnet in the circuit between *T′* and *M*; and arranging that its armature, when strongly enough attracted, shall bring two contacts together and short-circuit *M*. These two contacts could also be brought together by hand, and would then take the place of the key *K*.

121. Starters for Shunt Motors.—The *starter* of a shunt motor is different from that of a series one, provision having to be made for the shunt field circuit. The connections of such an one, with a no-voltage release, are given in Fig. 192; the actual switch, mounted on the front of an iron case containing the resistance, being shown in Fig. 193. Referring to the former figure, it will be noticed that the switch-arm *SA* is in the "on" position. The current entering from the mains *viâ* the double-pole switch *S*, proceeds to *X*, where it divides, part going through the field coil *F*, and the main current through the armature *A*. The armature current enters the "starter" at the terminal *Arm*, and traversing the switch lever, leaves by the terminal *Line*, and thence proceeds through *S* back to the supply mains. The field current from *X* and *F* enters at the terminal *Field*, traverses the coil of the "hold-on" magnet *E*, and thence completes its journey *through the whole of the resistance*, and through the switch-arm,

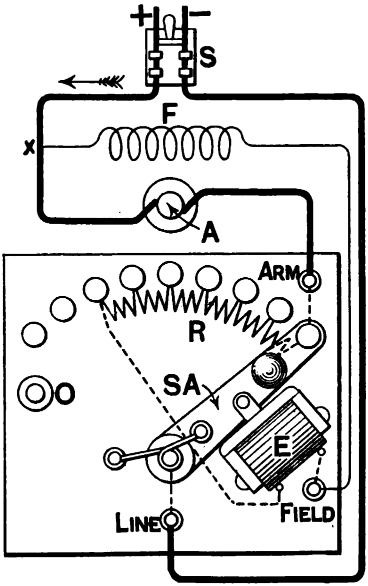


Fig. 192.—Connections of Starter for Shunt Motor (Ward Leonard).

to the terminal *LINE* on the other side of the supply circuit.

When the supply is cut off by opening *S*, or should the field circuit be accidentally broken, the magnet *E* will release the switch-arm, which will thereupon fly to the "off" stop *O*, the shock being taken by a spring buffer, as shown in Fig. 193.

FIG. 193.—Starter for Shunt Motor (Ward Leonard).

It should be noticed (in Fig. 192) that when the switch-arm is "off," *A* and *F* form a closed circuit with the resistance *R* and magnet *E*; the inductance of *F* has consequently no chance of causing destructive sparking when the current is shut off. In starting the motor, *S* is first closed, and then, as the switch-arm is slowly put on, the resistance *R*, which, to start with, is all in circuit with *A*, is

gradually transferred from *A*'s to *F*'s circuit. The value of *R* is too small to affect appreciably the current in *F*, which necessarily consists of a comparatively large number of turns of fine wire. This arrangement is adopted for the express purpose of rendering the breaking of the shunt circuit unnecessary. It is rendered clearer by the diagram Fig. 194, which gives the circuit connections of Fig. 192, and is similarly lettered but differently arranged. The two figures should be compared.

Simply arranged circuit diagrams such as these are very

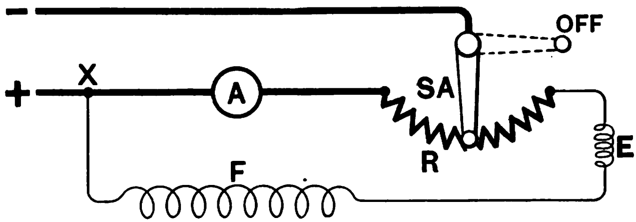


FIG. 194.—Circuit Diagram of Fig. 192.

useful in helping one to understand motor connections. Others are given in Figs. 197, 200, and 203.

Fig. 195 shows the connections, and Fig. 196 an elevation and plan, of a motor starter with two automatic releases. The first of these acts when the supply is cut off (*no voltage release*); and the second in the event of the armature current exceeding a given amount, as would happen if the motor were overloaded, and its speed and back E.M.F. were consequently much reduced; or if the attendant attempted to switch out the rheostat resistance too quickly. The latter is thus termed an *overload release*.

Referring to Fig. 195, *A* is the no-voltage release coil, which is in series with the field winding of the motor *M*; and *B* the overload release coil, which is connected in the main or armature circuit. *S* and *S′* are two switch-arms moving about the same centre, but independently of one another. Springs coiled about their spindles tend to pull them "off" in opposite directions, as shown by the curved arrows. Fig. 197 is a circuit diagram of the connections,

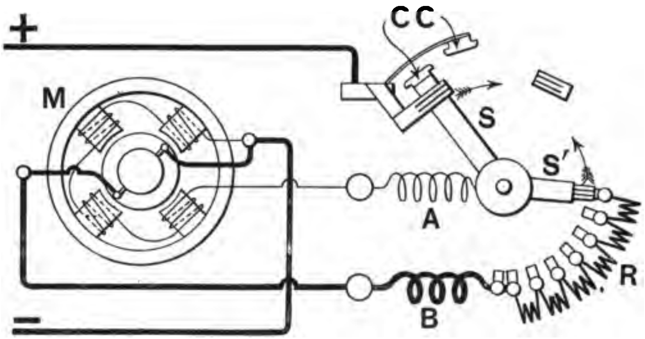


FIG. 195.—Connections of Motor Starter (Siemens).

parts of this corresponding with those of Fig. 195, being similarly lettered.

The starter is manipulated by the handle *H* (Fig. 196), which, when turned left-handedly, puts *S* "on"; and, when turned right-handedly, puts *S′* "on." *S* is shown "on" in both figures, and it acts as a main S.P. switch with auxiliary carbon contacts *C*, *C*. As will be noticed, putting *S* "on" completes the shunt circuit, and a hinged catch *C* (Fig. 196), carried on the arm *S*, engages with a fixed catch *C′* on the armature *a*, which by this time is drawn hard down on to

the pole of its magnet *A*. *S* is in this manner held "on"

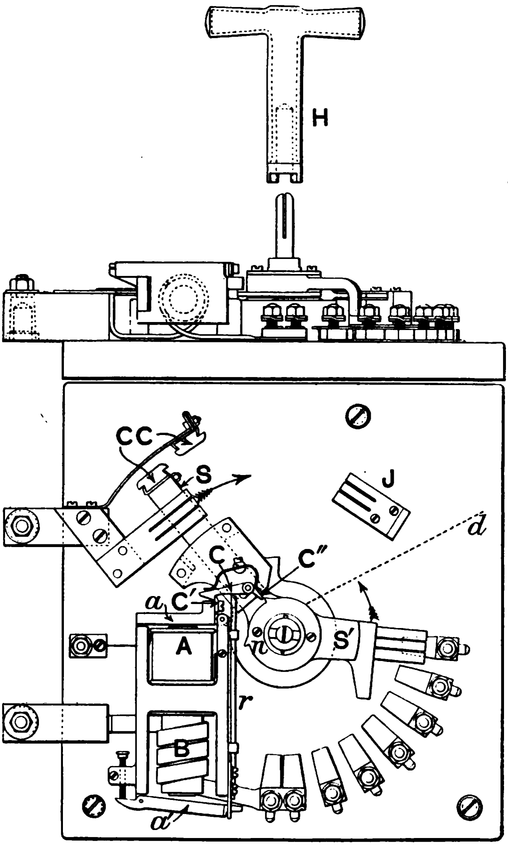


FIG. 196.—Siemens Motor Starter (Elevation and Plan).

against the tension of a coiled spring which tends to pull it

off into the stop-jaws *J*, the latter being unconnected with any part of the circuit.

While *S* is being put on, *S′* is in its off position, which is approximately indicated by the dotted line *d*. *H* being now turned right-handedly, *S′* first reaches the position shown in the figures, this completing the armature circuit through the whole of the resistance *R*. When the latter is all cut out, the notch *n* engages with the second hinged catch *C″* on *S*, and so locks *S′* in position.

When it is desired to stop the motor, the handle is

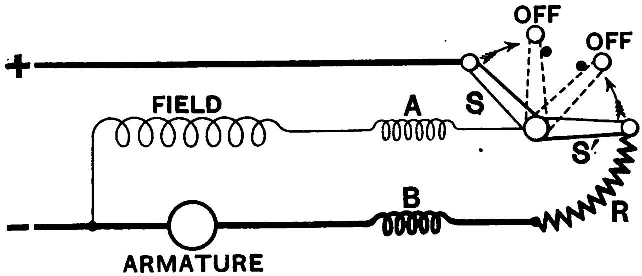


Fig. 197.—Circuit Diagram of Fig. 195.

turned left-handedly, this causing the catch *C″* to lift *C* off *C′* and so release *S*, *S′* at the same time travelling round to its off position.

Should the current be interrupted while the motor is running, the armature *a* will fly up, thus raising *C* and allowing *C″* to release *n*, *S′* then flying off. If, on the other hand, the current in the overload coil *B* gets too great, the armature *a′*, which normally is not attracted, will fly up, and in so doing will push up the rod *r* and knock *C* off *C′*, thus releasing both *S* and *S′*.

As explained at the commencement of this description, the overload release also acts if the attendant switches the resistance out of circuit too quickly, the current in *B* (*i. e.* in the armature circuit) rising above the normal.

122. STARTERS FOR SHUNT AND COMPOUND MOTORS.—The form of starter for use with a compound motor is

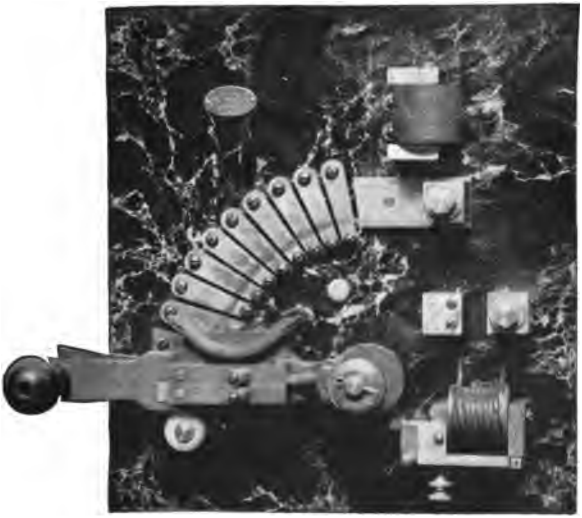


FIG. 198.—Starter for Shunt or Compound Motor (Sturtevant).

virtually the same as that employed with a shunt motor, the series winding being regarded as part and parcel of the armature circuit.

A starter with both *no-voltage* and *overload releases,* and suitable for either shunt or compound motors, is illustrated in Fig. 198; and a diagram of the connections is given in

Fig. 199. Referring to the latter, the current entering at the terminal marked +, passes through the magnet coil *M* of

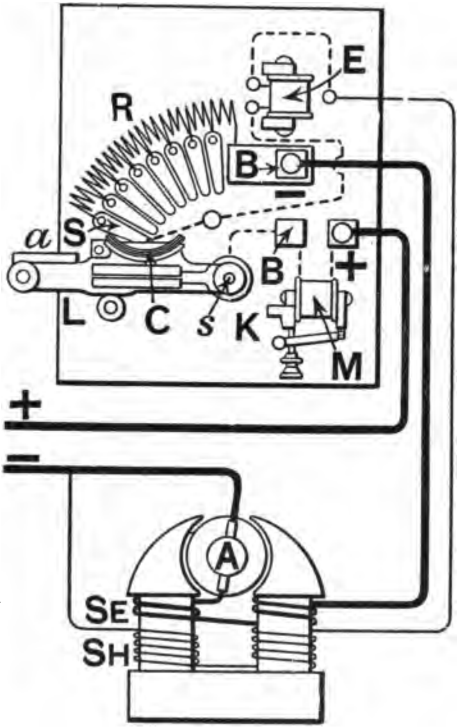


FIG. 199.—Connections of Starter for Shunt or Compound Motor (Sturtevant).

the overload release, to the switch-lever *L*, which, by the way, is shown in the "off" position. As soon as *L* is moved up to make contact with the first stud *S*, the

current divides; part going through the resistance *R* and *viâ* the – terminal to the series coil *SE* (if a compound motor) and armature *A*, and part through the electro-magnet *E* to the shunt winding *SH*. As the lever *L* is moved up towards *E*, the effect is to take *R* out of the armature circuit and put it into the shunt circuit. When the iron armature *a*, fixed on the switch lever, comes against the poles of *E*, the laminated copper brush *C* bears against the blocks *B*, *B*, and so affords a better path for the current than through

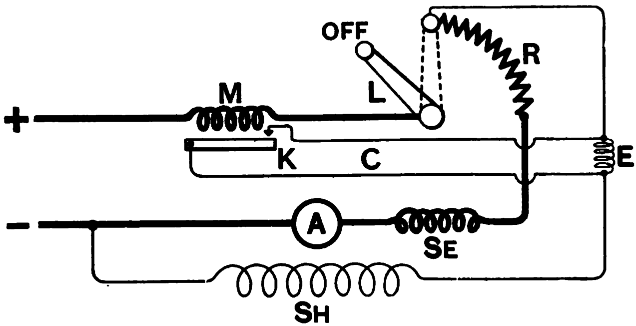


FIG. 200.—Circuit Diagram of Fig. 199.

the spindle *s*. Should the supply voltage fail, either temporarily or permanently, *E* will release *a*, and *L* will fly off under the tension of a helical spring coiled round its spindle *s*. If, on the other hand, there should be an overload on the motor, tending to pull it up and thus cause an excess of current to flow through the armature; this excess current, passing through *M*, will cause it to attract its armature, so bringing two contacts together at *K* which will short-circuit *E*, and cause the switch

to fly off. These connections between E and M are not shown in the figure, but they are indicated at C in Fig. 200, which is a circuit diagram of Fig. 199, and

FIG. 201.—Starter for Shunt or Compound Motor (Elec. Transmission Co.).

should be carefully compared therewith. When only the normal current is flowing, the attraction between M and its armature is not sufficient to pull the latter up. The

diagram (Fig. 199) should be compared with Fig. 198, which illustrates the actual apparatus. In the latter figure the armature of *M* is "on," and the contacts at *K* are closed, while in Fig. 199 the reverse is the case. The motor may be "shut off" by raising this armature by hand. A similar arrangement is shown at *M* in Figs. 201 and 202.

Fig. 201 gives a view and Fig. 202 the connections of a "starter" which possesses some novel features. Chief of these is an automatic magnetic clutch, which prevents the operator switching on the main current, should the field-magnet not be well excited, or should the pressure be too low; while it automatically releases the switch-arm if either the voltage falls or the current fails.

The handle-arm *A* is not attached to the switch-lever *L*, but is only held to it electro-magnetically when the conditions are suitable. Portions of *L* and *A* are of iron, and are fitted with pole-pieces extending across the face of a coil *K*, which surrounds the iron spindle of the switch; the combination forming the electro-magnetic clutch alluded to. The ends of this coil are at *E*. *C* is a temporary contact, the office of which will be explained presently; while *M* is the maximum current cut-out, and *H* a switching-off handle. The switch is shown "off" in the figure, and the switching-on is effected in the following manner. The handle-arm *A* is turned to the left so as to bring its pole-piece *P* against that (*P'*) of the switch-lever *L*. In doing this temporary contact is made at *C*, this energizing the field-magnets *FM* and the clutch-coil *K*, which are connected in series, as shown in Fig. 202. A pause of a few seconds is then made to allow the field-coils to become fully

excited; otherwise the clutch-magnet will not be sufficiently strong to allow A to draw L over to the right, a helical spring, which is fitted behind the base, tending to keep L in the "off" position. The due excitation of the

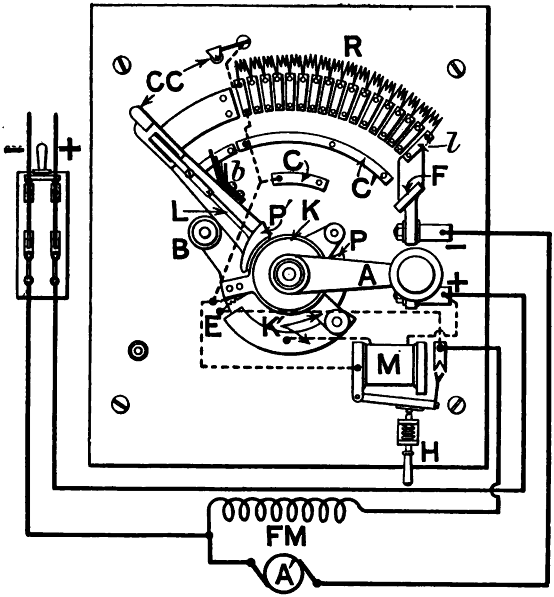


Fig. 202.—Connections of Starter for Shunt or Compound Motor (Elec. Transmission Co.).

magnets is thus assured. The switch-lever L may then be drawn slowly over the resistance contacts R, until the full "on" position is reached, whereon the handle-arm A will be locked by a spring detent, which is not observable in the figure, it being behind A. As A and L move

round, *A* leaves *C*; but the current for *K* by that time has another path *viâ* *L* and *C′*. Should the attendant attempt to switch on too rapidly, the current in the cut-out coil *M*, which is in series with the motor armature *A′*, becomes strong enough to raise its own armature. The effect of this will be that the clutch-coil *K* will be short-circuited, and *L* will be released from *A*, the spring before-mentioned bringing *L* once more to the "off" position against the rubber buffer *B*. This short-circuiting may also be effected

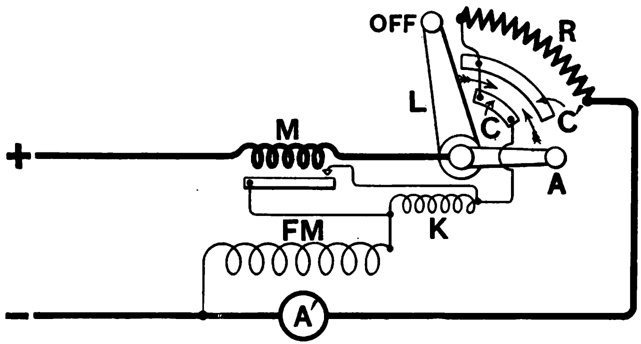


Fig. 203.—Circuit Diagram of Fig. 202.

by hand, by pushing up a small handle *H*; this raising the cut-out armature, and bringing together the short-circuiting contacts to the right of it. In this way the motor may be switched out of circuit and stopped. The frame containing the resistance wires is to be seen at the back of the slate base (Fig. 201).

The connections of the apparatus are shown in Fig. 202, which is lettered the same as Fig. 201, and Fig. 203 is a circuit-diagram of Fig. 202. *L* and *A* receive their current

through the rubbing contact *K′*, and when *L* flies off, the connection with *R* is finally broken through the carbon contacts *CC*. When *L* is full-on the brush *b* presses against *F*, thus affording an alternative and easier path for the main current than through the last resistance contact *l*. It will be understood, by the way, that the brushes making contact with *C*, and with *C′* and *R*, are on the undersides of *A* and *L* respectively.

123. Self-Starting Rheostat.—In a new class of motor starting gear, the gradual switching-out of the resistance is performed automatically, the attendant having nothing more to do than to close an ordinary switch when the motor is to be started.

A simple form of such apparatus, with its connections, is depicted in Fig. 204, the whole control of the motor being effected through an ordinary tumbler switch *T*. When this is put on, current flows from the + main through the solenoid of the electrically-operated main switch *M*, thus pulling up its iron plunger and laminated contact brush *b* which closes the main circuit. The actuating current then flows through *T* to the terminal 2 on the motor switch, thence to the first of the resistance contacts, and through the switch-arm *SA*, to terminal 5 which is connected with the negative main.

The main circuit being closed at *M*, the current divides at ×. The main portion goes to one terminal *T′* of the motor, and there again divides, the major part going through the armature *A* to terminal 3, thence through the resistance *R* (if in circuit) and switch-arm *SA*, to the negative main *viâ* terminal 5. The shunt current from *T′* passes through the field-winding *F*, then by terminals 4

and 5 to the − main. The shunt current from × enters at terminal 1, passes round the solenoid *S* to a contact stud *CS*, and then (on starting) through a contact spring *K*, to terminal 5 and the negative main.

The switch-arm *SA* is pivoted at *P*, and linked to an iron plunger *I* and dash-pot *D*. Thus when *S* is energized, *I* and *SA* are slowly drawn up, and the resistance *R* gradually cut out of the armature circuit. In its "off" position, *SA* short-circuits a resistance *r* inserted between the two last fixed contact plates. Thus, when *SA* is drawn up, *r* is open-circuited and

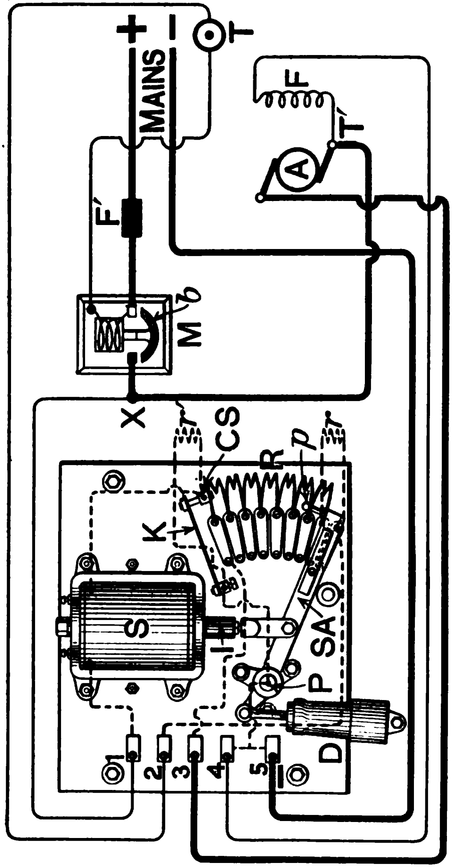


FIG. 204.—Self-starting Rheostat (Sturtevant).

placed in series with R between the terminals 2 and 3, that is to say in circuit with T and M; the current in the latter, however, remaining sufficiently strong to keep b up and the main circuit closed. Further, when SA is drawn right up, an insulated pin p carried by it bears against K, pushing it away from the contact stud CS, and thereby open-circuiting r', which is consequently thrown in series with the solenoid S. In this way the currents in M and S, which must be fairly large to start with, so as to give good pulls on the plungers, are permanently reduced when once the motor is started. r and r' are generally formed of a number of glow lamps, arranged in holders placed at the top of the rheostat above S, or in any other convenient position.

The motor circuit remains closed until T is put off, when b falls and the current is cut off at $\times$. SA then falls by its own weight, the dash-pot not acting in this direction, so that SA is not likely to stick. M might be replaced by a hand switch, but the chief reason for using it is that it acts as a low- and no-voltage release. That is to say, if the voltage falls, or the supply fails, the current in the solenoid of M is reduced or altogether cut off, as the case may be. Then M and SA will drop, and R be reinserted in the armature circuit; so that no heavy current can pass through the latter if the normal voltage suddenly comes on again. It might be thought that the reduction of current in S alone would release SA, but this would not be the case, unless the supply failed altogether; as directly SA began to drop, r' would be short-circuited, and the current in S thereby increased, so that the apparatus would probably "pump." To provide against over-load or excess current, a fuse or automatic cut-out would have to be inserted, say at F'.

124. **Reversible Motor Starter.**—Where motors are

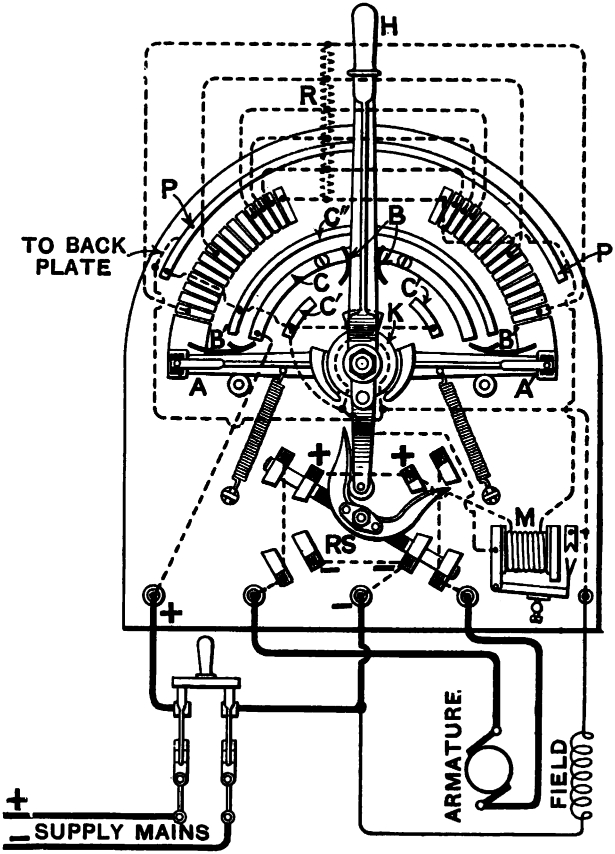


Fig. 205.—Reversible Motor Starter and Controller (Elec. Transmission Co.).

required to run in either direction at will, as with loco-

motives, tramcars, cranes, hoists, lifts, and so forth, it is necessary to have a current-reversing gear attached to the motor-starting switch. The construction of such a combination varies in nearly every case, as the requirements differ according to the machine which is to be driven.

A reversible motor-starter designed for a hoist is shown diagrammatically in Fig. 205. The handle-lever H is in its neutral position, and the two switch-arms A, A' are "off." If the motor is required to turn in, say, a clock-wise direction, H is moved to the right, and picks up A' by a magnetic clutch K, in exactly the same manner as described in connection with Fig. 201. If the motor is to turn in the opposite direction, H is moved to the left, and the arm A is thereby brought into operation. Although there is a separate series of resistance contacts for each arm, there is but one set of resistances, this being joined up to the contacts as shown at R, only a few of the connecting wires being drawn in. When H is moved to the right or left it operates the reversing switch RS by means of a heel-roller working in a U-shaped bearing mounted on the switch-arm. The four outer contacts of the switch are connected to the motor armature, and the switch changes the direction of the current through the latter, and consequently its direction of rotation (§ 108). In the position depicted, the current is flowing through the armature from the top to the bottom brush.

The left-hand + terminal is connected with the curved contact-piece C, and when H is moved in either direction, brush-contacts on its underside (indicated at B) connect C with one or other of the temporary contacts C', C', thus energizing the clutch-coil at K, and sending the current

through the field. The clutch-coil is also connected with the contact-piece *C''*, so that when either *A* or *A'* is moved up, the brush-contacts they carry (indicated at *B'*, *B'*) lead the current from *C* to *C''*, thus keeping on the current through *K* and the field. *B'*, *B'* also lead the current from *C* through the resistance *R*, thence through a wire connecting the two top resistance contacts with the overload coil *M*, and *viâ* *RS* to the motor armature. The action of *M* is as previously described (Fig. 201). When either arm *A* or *A'* is released, it is pulled off by a helical steel spring *S*.

At the top of the apparatus are two semicircular contact plates one behind the other, only the front one *P*, *P*, being shown. These are insulated from each other, and are connected to the ends of the coil *K*. Behind *H* is a contact trigger which normally short-circuits *K* by bearing on *P*, *P*, and its fellow. This is a special addition, and in consequence thereof the motor will only work so long as the operator has his hand on *H*, and clenches the trigger as well. Otherwise all sorts of accidents might happen. For instance, the operator might start hoisting or lowering and then leave the switch, while the load was in transit.

Without this device, the apparatus would be suitable for any constantly-running motor which had to be reversed occasionally.

Or if *P*, *P* were a single arched piece unconnected with the circuit, and notched all round so that, by means of the trigger on *H*, the lever might be locked in any intermediate position, thus keeping more or less of the resistance permanently in circuit, the apparatus would act as a *speed controller* as well as a starter. A controller such as is used in tramway work is described in § 131.

125. Features of a Perfect Motor Starter.—The features of a perfect motor starter are briefly as follows:—

(*a*) It should not be possible to switch the current on to the armature until the field coils are thoroughly excited, and unless the circuit pressure is normal.

(*b*) It should break circuit if the operator attempts to start the motor too quickly, or if the armature current becomes excessive, or if the supply fails, or the voltage drops very much.

(*c*) It should reinsert the resistance before breaking circuit.

There are numerous excellent forms of starting switch and controller other than those described, but the principles involved in the construction of such for simple series and shunt motors will be understood from the foregoing descriptions.

In § 131 something is said about tramway motor controllers.

126. Motor Calculations.—The design of motors, so far as concerns their ampere-turns of excitation, flux in field, number of conductors on armature, etc., etc., follows very much on the same lines as that of dynamos. Several points relating more or less closely thereto have been and will be dealt with in other paragraphs, and the subject will only be touched upon here so far as regards the working out of two or three special problems.

Problem I. To find the number of conductors for a 2-pole motor armature, given section of armature core,

H.P. required, supply pressure, and current at a given speed.

EXAMPLE.—A 2-*pole ring-armature motor is required to give out* 10 *H.P. when used on mains at* 200 *volts, and taking a current of* 50 *amperes, at a speed of* 500 *rev. per minute. The iron in its core has a nett cross-section of* 25 *square inches. Assuming an average flux through the core, how many turns must be wound on the ring?*

The average flux through a motor armature may be taken as 14,000 lines per square cm. In this case the total flux will be $25 \times 6{\cdot}5$[1] $\times 14{,}000 = 2{,}275{,}000$ lines.

$$\text{By § 110, H.P. of motor} = \frac{2\pi n T \times 60}{33{,}000}$$

$$\text{and } T = \frac{C \mathsf{F} N}{852{\cdot}3 \times 10^6} \qquad (\text{§ } 109)$$

$$\text{Substituting this value for } T\text{:—H.P.} = \frac{2\,\pi\,n\,C\,\mathsf{F}\,N \times 60}{852{\cdot}3 \times 33 \times 10^9}$$

In the present case we know H.P. $= 10$, $C = 50$, $\mathsf{F} = 2{,}275 \times 10^3$, and $n = \frac{500}{60} = 8{\cdot}3$. The quantity to be found is therefore N.

$$\text{By transposition :—} N = \frac{\text{H.P.} \times 852{\cdot}3 \times 33 \times 10^9}{2\,\pi\,n\,C\,\mathsf{F} \times 60}$$

$$i.e\ N = \frac{10 \times 852{\cdot}3 \times 33 \times 10^9}{2\,\pi \times 8{\cdot}3 \times 50 \times 2{,}275 \times 10^3 \times 60} = 790$$

That is to say, the armature must have 790 turns upon it.

Problem II. To find the H.P. and speed of a motor, knowing the number of poles, flux from each pole, size of armature, number of conductors thereon, and electrical input.

[1] 1 □ in. $= 6{\cdot}5$ □ cm.

EXAMPLE.—*A 4-pole motor having an armature 26 ins. in dia., and carrying 240 external conductors in series (§ 20), takes 280 amperes at 250 volts. The flux of lines from one pole = 9 × 10⁶. Assuming the field-magnets to be separately excited, and the armature to work with 92% electrical efficiency, find the speed and H.P. developed.*

(i.) Knowing the electrical input and the electrical efficiency of the armature, the H.P. developed is easily found.

Input = 250 × 280 = 70,000 watts = 93·8 H.P.

Then :—

$$\text{H.P. given out} : 93{\cdot}8 :: 92 : 100$$

$$\text{,,} \quad = \frac{93{\cdot}8 \times 92}{100}$$

$$= 86{\cdot}3 \text{ H.P.}$$

(ii.) Now to find the speed.

As shown on the opposite page :—

$$\text{H.P.} = \frac{2\,\pi\,n\,C\,\mathsf{F}\,N \times 60}{852{\cdot}3 \times 33 \times 10^9}$$

$$\text{and} : -n \text{ (rev. per sec.)} = \frac{852{\cdot}3 \times 33 \times 10^9 \times \text{H.P.}}{2\,\pi\,C\,\mathsf{F}\,N \times 60}$$

$$\text{Thus :—} \qquad n = \frac{852{\cdot}3 \times 33 \times 10^9 \times 86{\cdot}3}{6{\cdot}28 \times 280 \times 9 \times 10^6 \times 2 \times 240 \times 60}$$

$$= 5{\cdot}3 \text{ r. p. second, or } 318 \text{ r. p. m.}$$

As we are dealing with a 4-pole machine we multiply the flux from one pole by 2, this being the number of pairs of poles (§ 21).

127. MOTOR CALCULATIONS (*cont.*)—It is proposed here to consider a few more concrete problems relating to motors, the working-out of which will serve to elucidate various other points concerning motor calculations, in addition to those already dealt with.

EXAMPLE (a).—*A shunt motor, originally wound for use on* 120-*volt supply mains, has to be altered to enable it to be run off a* 240-*volt supply: the motor being required to possess the same efficiency, at the same speed, as before. What changes must be made in the sizes of the wires on the field-magnet and armature, the difference in the space occupied by the insulating material in the two cases being left out of consideration?*

In § 111 we saw that the expression connecting the current in and the resistance of the armature, with the working pressure and back E.M.F. was :—

$$C=\frac{E-\mathcal{E}}{R}$$

Hence the back E.M.F. :—

$$\mathcal{E}=E-C\,R.$$

And in § 114 it was proved that the electrical efficiency of a motor is proportional to :—

$$\frac{\mathcal{E}}{E}$$

In the present case, the motor, when rewound for the higher pressure, is to have the same efficiency; or in other words, the ratio $\frac{\mathcal{E}}{E}$ must remain unchanged.

Hence, since the working pressure is doubled, the back E.M.F. must also be doubled.

Referring to the formula given in § 111 :—

$$\mathcal{E}=\frac{N\,\mathbf{F}\,n\,p}{10^8}$$

it is evident that as n and p remain the same, to increase $\mathcal{E}$ we must increase either N or $\mathbf{F}$, or both. But $\mathbf{F}$ cannot well be increased, as the iron circuit remains the same in area as before; and if well proportioned when the motor was originally built, would certainly not permit of any

great increase in the flux. Consequently the number of conductors N must be doubled.

The size of the armature core remaining unaltered, the overall width of one turn (including insulation) must be reduced to one-half to get on twice the number of turns; or, neglecting the difference in the space occupied by insulation, the width of the copper must be reduced to one-half.

If the conductor be of rectangular section, its cross-section will then be half its original size; and there will therefore be just room for double the number of turns. If, on the other hand, it is of circular section, the cross-sectional area of one wire will be only one-fourth of its original value when the width of copper is reduced to one-half, as the area of a circle varies as the square of its diameter. But as four times the number of wires of the reduced size can be put in each core slot, and as the number of turns is to be doubled, the wires in each slot must be arranged in pairs, so that each turn consists of two wires in parallel. The cross-sectional area per slot will then be halved, as with the conductor of rectangular section.

Let us now consider the field-magnet circuit, where, as we saw, $\mathbf{F}$ must remain unaltered.

For a magnetic flux $\mathbf{F}$ (§ 23) the general equation is:—$\mathbf{F} = 1{\cdot}257 \times$ ampere-turns $\div$ magnetic resistance of circuit $(\mathbf{R}')$.

The amperes in the shunt circuit may be obtained by dividing the working pressure E by the resistance of the shunt winding R_{sh}: while the turns will clearly be equal to R_{sh} divided by the resistance of one turn R_t. Hence the above equation becomes:—

$$\mathsf{F} = 1{\cdot}257 \times \frac{E}{R_{sh}} \times \frac{R_{sh}}{R_t} \div \mathsf{R}'$$

i. e:—
$$\mathsf{F} = 1{\cdot}257 \times \frac{E}{R} \div \mathsf{R}'$$

As the value of F is to remain unaltered, and as E has been doubled; it follows that the resistance of each turn of the field winding must also be doubled, so as to keep the ampere-turns the same. The width of the winding, if rectangular, should be halved; and to fill up the space on the cores, the number of turns must be doubled; this giving half the current at double the number of turns, *i. e.* the same ampere-turns as before. If the wire is circular, its original diameter must be divided by $\sqrt{2}$.[1] The cross-sectional area will then be halved, and the resistance of each turn consequently doubled: and to keep the ampere-turns the same, and fill up the space on the cores, the number of turns must be doubled.

EXAMPLE (b).—*A compound-wound dynamo, when run at* 1400 *r.p.m., maintains a P.D. of* 240 *volts with a current of* 35 *amperes, its electrical efficiency being* 89 *per cent.: and the resistances of its armature and series windings are respectively* 4ω *and* ·42ω. *It is required to use the machine as a motor on* 240-*volt mains. What alterations would you make in it; and presuming it to work at the*

---

[1] In Chaps. *II.* and **IV.** it is explained that the areas of circular wires are proportional to the squares of their diameters. Conversely, it follows that the diameters of wires are proportional to the square roots of their areas. If a be the area of a wire of diameter d, quartering the area will only halve the diameter, *i. e.* $\frac{a}{4} \propto \frac{d}{2} = \frac{d}{\sqrt{4}}$. Similarly, if we halve the area, *i. e.* divide it by two, we must divide the original diameter by $\sqrt{2}$.

same efficiency as before, at what speed would it run, and what H.P. would it give out?

From what was said in § 118, it will be evident that if the motor is required to run at an absolutely constant speed, the shunt and series windings must be differentially connected. If, on the other hand, great starting torque is of more importance than constant speed, the two windings must be cumulative in effect.

If the dynamo winding is cumulative, as is usual, it will act differentially, without any alteration of connections, when current is sent through it as a motor. If, however, the motor winding is desired to be cumulative, the connections of the series coil must be reversed.

From § 114 we may express the percentage electrical efficiency of a motor as:—

$$\frac{\mathsf{E} \times 100}{E},$$

where E is the back E.M.F., and E the applied pressure.

In the present case:—

$$89 = \frac{\mathsf{E} \times 100}{E} \qquad (a)$$

and $E = 240$ volts.

$$\therefore \quad \mathsf{E} = \frac{240 \times 89}{100} = 214 \text{ volts.}$$

Considering the machine as a dynamo we have:—

$$C = \frac{\mathsf{E} - E}{R}, \text{ so that:—} E = \mathsf{E} - CR \ (b) \ (\S\ 111)$$

where E becomes the terminal P.D. and E the E.M.F.; C being the current in, and R the resistance of the armature and series coil.

$$\mathsf{E} = \frac{N \mathbf{F} n p}{10^8} \qquad (\S\ 111)$$

$\frac{N\,F\,p}{10^8}$ being a constant in any given case, and calling it K, we may write:—

$$E = K n \qquad (c)$$

The value for R being $\cdot 4 + \cdot 42 = \cdot 82\omega$, E 240 volts, C 35 amperes, and n $\frac{1400}{60}$, from (c) and (b) we get:—

$$240 = K\frac{1400}{60} - 35 \times \cdot 82$$
$$= 23\cdot 3\,K - 29$$
$$\therefore K = \frac{269}{23\cdot 3} = 11\cdot 5.$$

Then by applying equation (c) to the machine as a motor we have:—

$$n = \frac{E}{K} = \frac{214}{11\cdot 5} = 18\cdot 6 \text{ r.p. second}$$
$$= 18\cdot 6 \times 60 = 1116 \text{ r.p.m.}$$

It now remains to find the H.P. given out by the motor.

This by § 114 is evidently:—

$$= \frac{E}{746} \times C$$
$$= \frac{E}{746} \times \frac{E - E}{R} \qquad (\S\ 111)$$
$$= \frac{214}{746} \times \frac{26}{\cdot 82}$$
$$= 9 \text{ H.P.}$$

128. To Test the H.P. and Efficiency of a Motor.—The brake horse-power of a motor, *i. e.* the horse-power actually given out by the motor-pulley, may be measured by a *brake* or *absorption dynamometer*. As

is indicated by the name, such a device measures the power by exerting a braking effort on the driven pulley, the power being absorbed in the process of measurement. *Transmission dynamometers*, on the other hand, will measure the power given out, while the motor, etc. is doing its work in driving a machine, without absorbing any of the power. It is not proposed to consider this class, however.

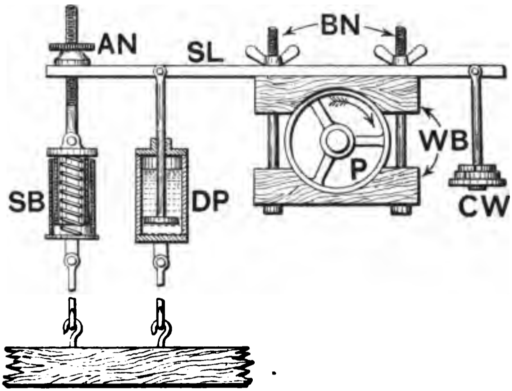


FIG. 206.—Prony Brake.

There are various forms of absorption dynamometer, probably the best known being the *Prony brake*. This and its manner of application are illustrated in Fig. 206. Here *P* is the motor-pulley, and *WB* two wooden blocks partly embracing the pulley, and clamped thereon by the bolts and nuts *BN*. These same bolts and nuts serve to fix a rigid *steel* lever *SL* to the upper block. *SL* carries a counterweight *CW* at one end, while at the other is a

hole through which passes an arm carrying an adjusting nut *AN*, and connected to a spring balance *SB* anchored to the floor.

The test is taken as follows:—The wooden blocks being loose on the pulley, the counterweights *CW* are adjusted until the weight of *SL* is balanced, *AN* being at such a height that *SL* is level. The motor is then started, and the blocks *WB* are tightened up until the revolutions are reduced to the speed at which the power is to be taken. At the same time *AN* is screwed down until *SL* is once more level, the tendency of the motor being to tilt it in the direction of rotation, which is indicated by the curved arrow. Now let n represent the number of revolutions per minute of the motor shaft, as ascertained by a speed-counter, P the reading in lbs. of the pull on the spring-balance, and r the horizontal distance in feet between two vertical lines passing through the centres of the motor shaft and the spring balance respectively. Then:—

$$\text{Brake H.P.} = \frac{2\pi\, r\, n\, P}{33{,}000}$$

$$= \cdot 0001904\, r\, n\, P$$

$\dfrac{2\pi}{33{,}000}$ (= ·0001904) being a constant.

In order to steady the indications of the spring balance, it is sometimes of advantage to link up some sort of a dash-pot by the side of it, as represented by *DP* in the figure.

Fig. 207 illustrates a new form of brake dynamometer in which the braking is performed electro-magnetically. C' is an exciting coil joined up to terminals at T, its function being to energize an electro-magnetic system similar to the claw-shaped magnets often used in

alternators; the poles being alternately N. and S., and excited by the single coil C'. Two of these poles are at N, N. This electro-magnet, which carries a lever L with sliding weight C, is mounted on ball bearings, and is capable of rotating concentrically with the shaft through a small angle. The front lever and smaller weight are not now used, so we need not consider them. The shaft carries a driving pulley P, and the latter drives an iron cylinder IC which revolves round the magnet. When IC is rotated, eddy currents are generated in it by the field of the magnet, and these eddy currents exert a braking effect on the rotating cylinder; the action being similar to that of a dynamo with a short-circuited armature. When the power, say of a motor,

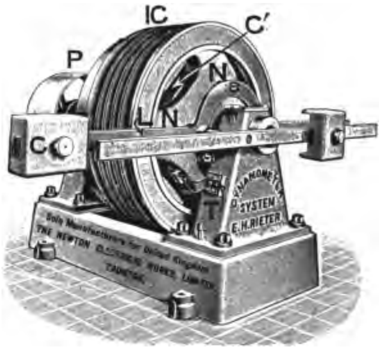


FIG. 207.—Rieter's dynamometer (Newton Electrical Works).

has to be measured, the motor is geared to the dynamometer either by means of a belt or a coupling. The exciting current, which is derived from a direct-current supply (an accumulator being the best source), is then adjusted by means of a rheostat, until the tendency of IC to tilt the lever L with its weight is just resisted. Then the power absorbed by the brake, which is that of the motor under test, is given by the formula :—

$$\text{Brake H.P.} = \frac{2\pi nml}{33{,}000} + \frac{n}{K}$$

Here n are the r.p.m., m the value of the weight in lbs., and l the distance in feet between its centre and that of the shaft, K being a constant depending on the size of the machine. The product $m\ l$ is the *moment* of the weight, or, in simple language, the *leverage*.

It will be seen that the power is measured in much the same manner as with the Prony brake; the only difference being that the retarding force is electro-magnetic and not mechanical friction. There is thus no liability to "seize," and consequently no violent vibrations of the lever, the readings being easily taken. The mechanical energy absorbed through the pulley P is transformed first into electrical energy, in the form of eddy currents; and then into heat, the latter being dissipated by the rotating ring IC, the surface of which is ribbed to assist it in throwing off the heat into the air.

If it is required to test the efficiency of a motor at any given power, the motor is belted to the dynamometer, and the weight adjusted so that, by the above formula, the desired power will be absorbed when the exciting current is on, and the lever horizontal. If the electrical power taken by the motor, as ascertained by voltmeter and ammeter, is W (watts), and that absorbed by the dynamometer is P (horse-power), the commercial efficiency of the motor will be:—

$$\left(P \times 100\right) \div \frac{W}{746} \qquad (\S\ 113)$$

*129. ELECTRIC TRAMWAYS AND RAILWAYS.—Electric tramway and railway systems may be classified as follows:—

(*a*) The trolley-wire or overhead system.

(*b*) The open-conduit or slot system.

(*c*) The closed-conduit or surface-contact system.

(*d*) The three-rail system.
(*e*) The four-rail system.
(*f*) The battery system.

This is also their order of importance so far as tramways are concerned, the trolley-wire system being the most used and the battery system the least. With railways, on the other hand, systems (*d*) and (*e*) are almost exclusively employed in this country.

In the *trolley-wire system* the current is collected from the trolley-wire overhead by a *trolley-arm* or *pole*, and is led thence through the motor or motors, and then through the frame, wheels, and rails back to the generating station. The trolley arm carries a wheel or bow mounted on an insulated swivel head, an insulated conductor connected with this passing down inside the trolley-pole.

The *slot system* differs from the foregoing in that the insulated charged or "live" conductor is placed underground in a conduit. Contact is made therewith by means of a "*plough*," which carries spring contact surfaces that rub against the conductor, the current being led therefrom through insulated wires to the motor. The plough is carried at the end of an arm passing through a narrow slot at the top of the conduit, and fixed to the frame of the tram-car; the arm being hollow and containing the conductor (or conductors) leading up from the plough. The return circuit is made either through the rails or through a second conductor laid in the conduit.

In the *surface-contact system* the charged conductor is completely enclosed in an underground conduit; and insulated contact studs, projecting slightly above the level of the track, are placed at every few feet. As a car passes over

the studs, the latter are automatically rendered "live," or, in other words, are connected with the conductor underground; and a rubbing "shoe," "slipper" or "skate" conducts the current to the motor, the rails being used as the return circuit. When the car has passed, the studs are automatically put out of circuit until the next one comes along. There are various ingenious methods for connecting the studs with the charged conductor just at the time that the car passes.

All the English electric railways at present working employ either the *three-rail* or *four-rail system* (chiefly the former), but these systems are only applicable to tramways with enclosed or semi-private tracks over which no other vehicles run. In the three-rail system, the current is led from the generating station along an insulated rail of copper or steel raised a few inches above the level of the track, and placed between or at one side of the car rails. A rubbing "shoe" or "slipper" carried by the car makes contact with this insulated conductor, and the current, after passing through the motor or motors, returns *viâ* the ordinary rails. The four-rail system differs from the above in that an insulated return conductor or rail is used.

In the *battery system* each car carries a secondary battery, which is charged at the generating station.

The trolley-wire or overhead system is much cheaper than any of the others, which at once explains why it is so extensively favoured. In the early days, great outcry was raised as to the unsightliness of the overhead work, and of the numerous poles; and as to the danger of the charged trolley-wire. The æsthetic objections are now proved to have been greatly exaggerated; and the danger through

breakage of the trolley-wire, or of shock therefrom, has been minimized by strong construction and efficient safety devices.

The open-conduit system is expensive to install as well as to maintain; it being not altogether an easy matter to keep the conduit free from water, mud and dirt, or to maintain the insulation of the conductor. The comparative inaccessibility of the latter is also a great drawback, and there is considerable friction and wear and tear between the plough-arm and the sides of the slot.

The surface-contact or closed-conduit system is free from most of the above-mentioned disadvantages, and is somewhat less expensive than the open-conduit. On the other hand, the row of slightly-raised studs and the contact skate form, at best, a clumsy and inefficient way of collecting the current. Moreover, the studs interfere with and suffer damage from the horse and other traffic, and there is considerable leakage thereat.

Were it not for the weight, inefficiency, and rapid deterioration of the storage battery, the accumulator system would be the ideal one; for the enormous expense of leading the current over every portion of the track, and providing for its return, would be avoided. Although battery-cars have been tried several times, they have never proved a decided commercial success, at any rate in this country. A short section of the Birmingham tramways is, however, worked on this system, this being the only example of such in the United Kingdom. As road vehicles of various descriptions are driven by accumulators, it is not improbable that some future radical improvement in secondary battery construction may eventually render them economic-

ally possible on tramway systems where gradients are few and low. A road car is described in § 115.

There are, at the time of writing (May 1903), over a hundred tramway systems worked with the overhead trolley; but only one (at Wolverhampton) on the surface-contact system. The open-conduit system is being introduced by the London County Council on the tramways south of the Thames, and there is a short length of line of this description at Bournemouth. It is proposed to inaugurate a *trolley-bus system*, i. e. ordinary road buses taking current from a trolley-wire, at Stroud, Gloucestershire.

As already mentioned, the third rail is not used on open tramway tracks, but there are some six so-called tramways, which are really light railways, worked on this method; these being at Brighton beach, Bessbrook-Newry, and on the piers at Herne Bay, Ryde, Southend, and Walton-on-the-Naze. The first three tube railways constructed in London are worked on this system; but some of the new ones will have four rails, the two conductor-rails being fixed on the side of the tunnel. The Liverpool Overhead Railway belongs to the four-rail class, both the conductor-rails being between the ordinary ones.

Some particulars as to the methods of distributing the current from the generating station over the tramway or railway track are given in §§ 228 and 236.

130. TYPICAL TRAMCAR MOTOR.—Figs. 208 and 209 show a 25 H.P. tram-car motor, and Fig. 210 a tram-car truck fitted with two of these. The wheel axle (Fig. 210) passes through the two front bearings on the motor frame, and a pinion on the armature shaft (Fig. 208) gears with a spur-wheel on the same axle. The lower half of the motor

case is hinged to allow the commutator and armature to be got at; and it will be noticed that the motor has four poles, two in each half of the case. The poles in the lower or hinged half are clearly shown, the slots in them being ventilating apertures which pass right through the case. These slots are protected on the outside by hoods which allow the heated air to escape, but prevent dirt from getting in. One of these hoods may be seen above the

FIG. 208. **Tramcar Motor (Brush Elec. Eng. Co.).** FIG. 209.

foremost bearings in Figs. 208 and 209, and the same is also discernible on each of the motors in Fig. 210.

The armature bearings may be bolted either to the top half of the motor as in Fig. 208, or to the bottom half as in Fig. 209.

Early tramcar motors were 2-pole, and the 4-pole form was afterwards adopted, as the normal speed of the armature is lower, and it is then possible to drive direct on to the wheel axle without the use of a countershaft.

131. TRAMCAR CONTROLLER.—The *controller* forms the connecting link between the driver and the motive

power of the car; one form of such, with the front opened to

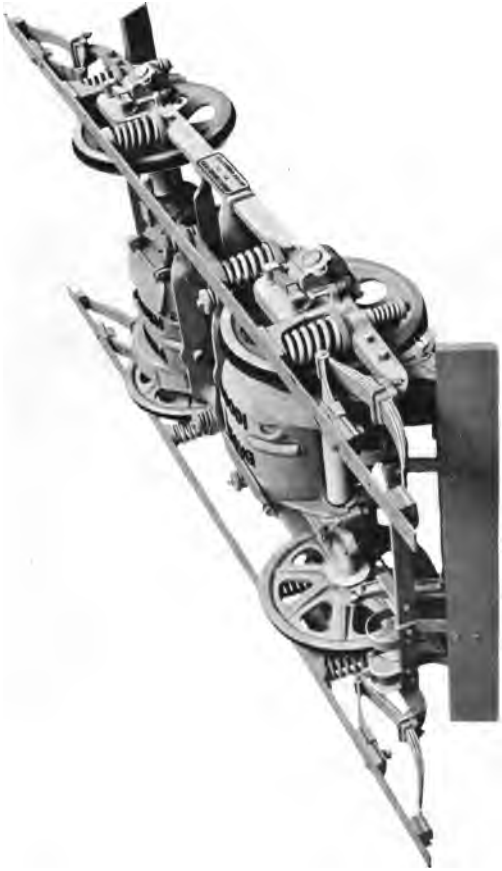


FIG. 210.—Tramcar Truck (Brush Elec. Eng. Co.).

show the mechanism, being given in Fig. 211. At the top are

two handles, by means of which the driver performs all the electrical operations of starting, stopping, speeding, reversing, and braking the car. The car is also fitted with

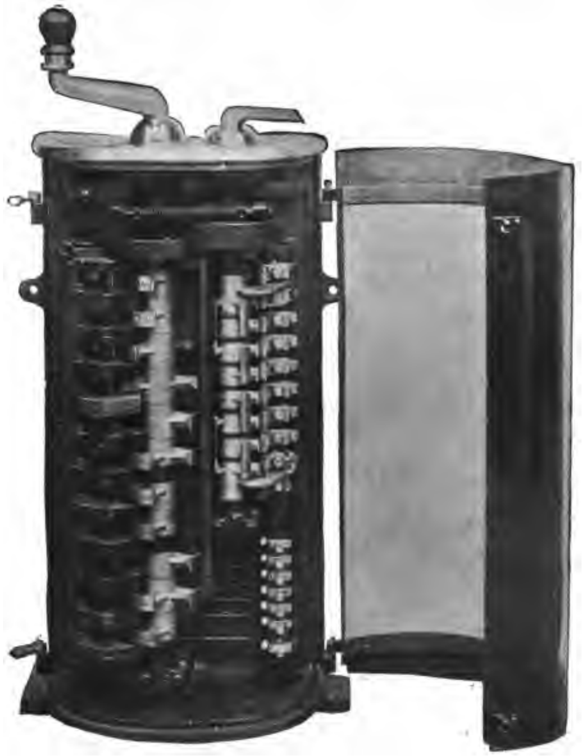


Fig. 211.—Tram-Motor Controller (Brush Elec. Eng. Co.).

mechanical brake gear, but with this, however, we are not concerned. The larger handle starts, varies the speed of, or shuts the current off from the motors; while the smaller

one alters the direction of the current, and therefore also the direction of travel. The latter has besides a third position, in which the current is cut off from the motors altogether, and the latter are short-circuited on themselves,

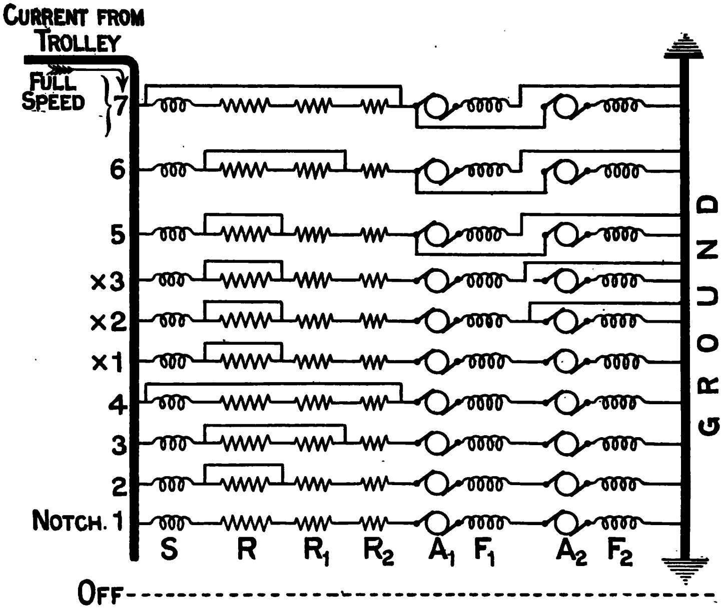


FIG. 212.—Controller. Diagram of Connections.

thus acting as dynamos, and exerting a braking effect. This device is termed an *electric brake.*

Such controllers are frequently referred to as *series-parallel controllers,* from the fact that the variations of speed are secured by connecting the motors up either in series or in parallel, or in combination with resistances.

The construction of the controller shown in Fig. 211 is briefly as follows. A vertical wooden spindle, operated by the large handle, carries a number of metal collars and projecting pieces, which make contact in a definite order with fixed contact pieces. According to the position of the handle, the motors and resistances are connected in a number of different ways, which will be explained presently. The smaller handle actuates a similar but shorter spindle. The contacts operated by the larger handle have flat solenoids on each side of them, the contacts and solenoids being arranged alternately. The main current flows through these solenoids, and the magnetic fields due to the latter act as *blow-outs* for any sparking which may occur at one or other of the contacts, when the circuit-connections are changed; this action being somewhat similar to that of the Thomson-Houston lighting arrester (Chap. II.). The large handle has seven "effective" and three "transition" positions or notches; besides its "off" position, in which all current is shut off from the motors. The connections at each of these positions are shown in Fig. 212, the left-hand vertical thick line representing the path of the current from the trolley, and the right-hand one *ground* or *earth*. In this diagram S stands for the solenoid blow-out coils, R, R_1, and R_2 are different resistances, while A_1 F_1 and A_2 F_2 are the armatures and fields of the two motors. Turning the handle from the OFF position to notch 1 starts the tram, with the two motors and all the resistances in series. At notch 2, R is cut out; at notch 3, R and R_1; and at notch 4, all the resistances as well as the solenoid coils, the motors then running in series.

Notches $\times 1$, $\times 2$, and $\times 3$ are "transition" connections

preparatory to throwing the motors from series to parallel, or *vice versâ*. At × 1, the blow-out coils and part of the resistance is put back in circuit; at × 2, motor No. 2 is short-circuited; while at × 3, it is cut out. At notch 5, the motors are in parallel, with some of the resistance in circuit; at notch 6, all but the last section of resistance is taken out; while at notch 7, all resistance and the solenoids are out of circuit, the motors then taking the full line pressure, and the tram running at its best speed if on the level.

The small handle has three positions besides "off." The first turns on the current; the second reverses its direction, for running backwards; while the third, called the emergency stop, short-circuits both motors, and causes them to act as brakes.

132. Power Required to Drive Trams, etc.—The power necessary for propelling any vehicle is found by multiplying the resistance to motion by the speed. The resistance to continued motion depends on:—(i.) the weight of the vehicle;[1] (ii.) the condition of the road or rails; (iii.) air or wind friction; (iv.) the rising or falling gradient, if any; and (v.) the speed attained.

Let $H.P.$ = power required, W = rolling weight in tons, K = resistance to motion along the level (expressed as "tractive effort" in pounds required to pull each ton of weight), S = speed of vehicle in miles per hour, n = number of feet along incline (if any) to each foot of vertical rise or fall.

[1] The weight of the vehicle should of course include that of the passengers or goods it is destined to carry. This total weight is sometimes referred to as "rolling weight."

Then :— $$H.P. = SW\left(\frac{K}{375} \pm \frac{6}{n}\right)$$

$\frac{6}{n}$ is a + quantity with an up gradient, and a − quantity with a down gradient, for in the latter case the propulsion is assisted by gravity.

The determination of K (resistance to motion) is not an easy matter, as it depends, among other things, on the state and character of the rails or road, and the friction on the curves. For the purpose of a simple example, we will assume that K on a level straight tram line $= 30$ pounds per ton.

EXAMPLES.— (a) *An electric tram-car, of* 12 *tons rolling weight, is required to run up an incline of* 1 *in* 50, *at a speed of* 8 *miles an hour, what is the power required?*

Here $W = 12$, $K = 30$, $S = 8$, and $n = 50$.

Then :— $$\text{H.P.} = 12 \times 8\left(\frac{30}{375} + \frac{6}{50}\right)$$
$$= 96 \times \cdot 2$$
$$= 19 \cdot 2.$$

(b) *In the above example, supposing the total or combined efficiency of the motors and gearing is* 60%; *what electric horse-power must be supplied, and what current will be required, if the pressure is kept constant at* 500 *volts?*

The actual horse-power necessary to drive the car has been found to be 19·2; but this represents only 60% of the electrical horse-power put into the motors. Calling the latter E.H.P., it is clear that :—

$$\text{E.H.P.} : 19 \cdot 2 :: 100 : 60$$

$$i.e.\ \text{E.H.P.} = \frac{1920}{60}$$
$$= 32 = 32 \times 746 = 23{,}872 \text{ watts.}$$

The current required will be $\frac{23{,}872 \text{ watts}}{500 \text{ volts}}$ = nearly 48 amperes.

(c) *A short electric train, with a total or rolling weight of* 50 *tons, runs up an incline of* 1 *in* 90. *The motors and gearing are such, that for every ampere passing through the armature, there is exerted a tractive effort of* 10 *pounds. The resistance to traction on the level is, say,* 28 *pounds per ton. How much current, and what horse-power, would be required to propel this train up the incline at a speed of* 20 *miles per hour?*

(i.) First find the horse-power necessary to propel the train at 20 miles per hour.

$$\text{H.P.} = SW\left(\frac{K}{375} \pm \frac{6}{n}\right) \qquad \text{(p. 386).}$$

In the present instance:—$S = 20$, $W = 50$, $K = 28$, and $n = 90$.

$$\begin{aligned} \text{Then H.P.} &= 20 \times 50\left(\frac{28}{375} + \frac{6}{90}\right) \\ &= 1000\,(\cdot075 + \cdot067) \\ &= 1000 \times \cdot14 \\ &= 140 \text{ H.P. (for speed of 20 miles per hour).} \end{aligned}$$

(ii.) Secondly, we have to find the necessary current, given that each ampere passing through the armature will exert a tractive pull of 10 pounds.

140 H.P. $= 140 \times 33{,}000 = 462 \times 10^4$ foot-pounds per minute: and at the speed given, the train moves through $\frac{1760 \times 3 \times 20}{60} = 1760$ feet per minute.

Having calculated, as above, the power in foot-pounds per minute, and the space moved through by the train in that time; by dividing the former quantity by the latter,

we shall get the tractive effort or pull necessary, in pounds.

Thus :— $\frac{462 \times 10^4}{1760} = 2625$ pounds force.

As each ampere exerts a tractive effort or pull of 10 pounds, the current required will be $\frac{2625}{10} = 263$ amperes.

This large current, it should be remembered, is only necessary while the train is on the incline.

133. ELECTRIC CARS.—Ordinary electric tram or single train-cars, or extra large road vehicles, are generally fitted with two motors, each of from 10 to 25 horse-power; or from 20 to 50 horse-power in all. The use of two motors offers the primary advantage of making it easier to start the car, because, as the motors are geared to separate axles, the grip of four wheels is brought to bear on the rails or road. Another advantage is, that if one motor becomes disabled, the car can still be worked by the other one. Again, it is easier to regulate the speed of the car without much waste through resistances; as the armatures and fields of the two motors can be joined up, with small resistances, in various series and parallel combinations; through the medium of a series-parallel controller (§ 131).

From twenty to fifty horse-power (or thereabouts) seems a lot to put into a tram-car; but then it must be remembered that this maximum power is only used at intervals; to enable the car to start quickly, and to work up inclines and round curves at a good speed. On the flat, and when once started, the horse-power absorbed is probably not more than from 5 to 10: this depending on the size of the car, on the speed, and on the load.

In contrasting these figures with the power of two horses,

which may be taken as something less than 2 horse-power; it should be remembered that, on the flat, the possible speed of a fully-laden car driven by electricity or drawn by horses is very different: while up ordinary gradients, the horses can only go at a walking pace, the services of a third one being often called into requisition. Then, again, electric cars are generally very much larger, and carry a much greater number of passengers, than is usual with horse-cars.

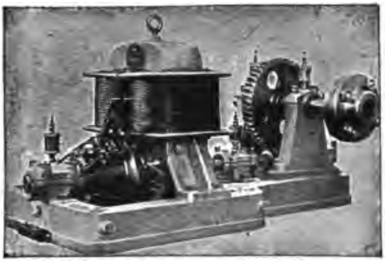


FIG. 213.—Motor with Worm Gear (E. Scott and Mountain).

*134. APPLICATIONS OF MOTORS.—Electric motors for general purposes are constructed to work at the same pressures as the incandescent lamps employed in interior lighting; and now that electricity supply has become so general, the use of motors is increasing rapidly. Anything like a full description of these uses would be impossible here, as it would require a voluminous treatise. In short, motors may be applied to any and every kind of machine; from the working of large lifts, cranes, and pumps, and indeed the whole set of machinery in a factory, down to the running of domestic sewing-, boot-, and knife-cleaning, washing, mangling, and numerous other machines. The enormous advantages possessed by electric motors must be clear to all who have any practical knowledge of applied electricity, so that we need not enlarge upon them. Various examples of motor gear and motor-driven ma-

chinery are illustrated in the following figures, and brief descriptions of each are given.

Fig. 213 shows a 2-pole undertype motor fitted with worm-gearing, through which the power is applied to whatever machine has to be driven, the speed being at the same

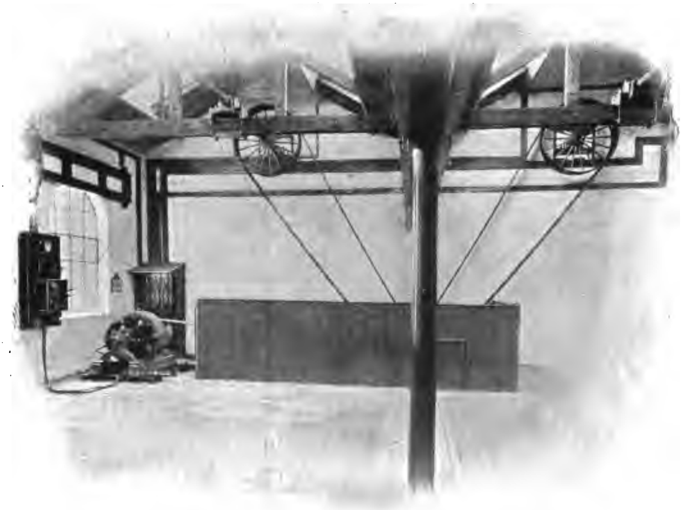


FIG. 214.—Motor driving Countershaft (Mather and Platt).

time reduced. The lower half of the worm runs in a bath of oil, such gearing requiring to be well lubricated. In some cases, the whole of the worm or other speed-reducing gear is immersed in an oil bath. It will be seen that the machine is fitted with unusually long brushes, which will last a long while with frequent trimming and constant wear. It was mentioned in Chap. *IX.* that most

types of direct-current dynamo will act equally well as motors; and in this connection it should be observed that the motor illustrated in Fig. 213 is of the same general construction as the dynamo in Fig. *203*.[1]

Fig. 214 shows a 4-pole motor driving through belting on to a countershaft, and thence on to two lines of shafting. Adjacent to the motor is a switchboard on which are fixed the starter and controller, main switch, and ammeter.

FIG. 215.—Motor-driven Drilling Machine (Mavor and Coulson).

An enclosed motor operating a vertical drill through toothed-wheel reducing gear, is depicted in Fig. 215. A pinion on the armature shaft gears into a spur-wheel on a countershaft, which forms also the lower cone shaft of the drilling machine. The switch and other regulating gear is placed in a box mounted between the two vertical posts of the drill frame.

Fig. 216 shows a motor with toothed-wheel reduction gear, which is mounted on the motor itself, and is completely enclosed; the top half of the cast-iron casing being removed

[1] *Vol. I.* Fifth edition.

in the figure to enable the gear to be seen. The driving pulley is at the other end of the shaft carrying the spur wheel. Matters are so arranged that the brackets holding the countershaft bearings may be bolted in at least three different positions. Thus the countershaft may be raised above the motor, or brought round to the near side. The

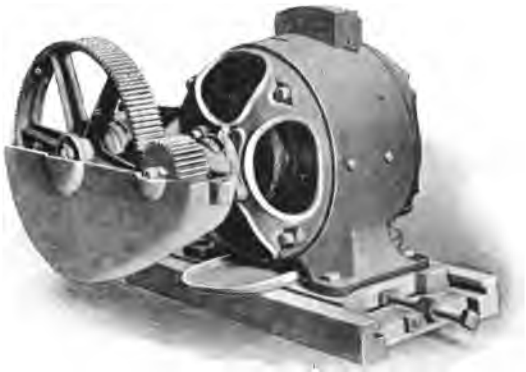


FIG. 216.—Motor with enclosed Reduction Gear (British Thomson-Houston Co.).

machine, it will be observed, is mounted on a slide base with belt-tightening bolts.

Fig. 217 depicts an electrically-driven band-saw, spur reducing gear being employed. The motor is wholly enclosed to protect it from sawdust, etc.; but the commutator and brushes may be readily got at by raising the hinged upper half of the case enclosing them.

Where the driven machine runs at a high speed no reduction gear is necessary. Thus in the saw bench in Fig. 218, the saw is mounted on the same shaft as the

motor armature, and therefore runs at the same speed. The motor is enclosed, the hinged cover above the right-hand bearing giving access to the commutator. The starter is also enclosed, this particular type being operated by a hand-wheel outside the glass-fronted cast-iron box which contains it.

The reader will be familiar with the usual forms of electrically-driven fan, which range in size from those which may be stood on a table, to those which are fixed in a window or wall aperture. An improved form of such, which, from its action, is termed by its makers the *punkah fan*, is illustrated in Fig. 219. The motor is free to turn partly round from side to side on ball bearings on its pedestal. In front of the fan blades are mounted three deflecting blades or sails, and these being set at an angle, the current of air impinging on them causes their frame and the motor to turn to one side or the other. When the limit of movement in one direction is reached, the blades are automatically reversed, and movement is set up in the opposite direction. Thus the current of air

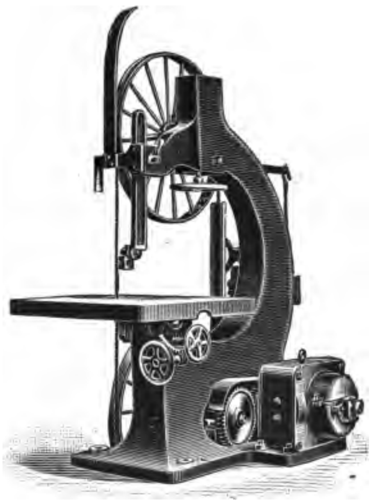


FIG. 217.—Motor-driven Band Saw (W. B. Haigh and Co.).

from the fan is swept round from side to side, and a much more effective disturbance of the air results. Both the rate and range of oscillation are adjustable.

A very effective form of ceiling fan is shown in Fig. 220, where *M* is the motor, the connecting wires from which pass up inside the supporting tube. The blades, which

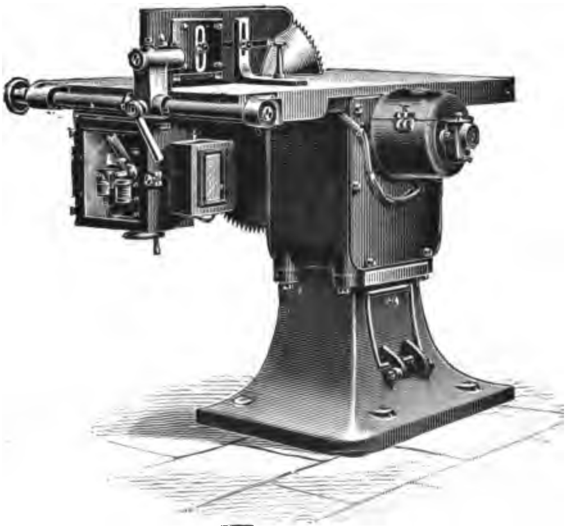


FIG. 218.—Motor-driven Saw Bench (W. B. Haigh and Co.).

each measure some 2½ feet in length, are made sometimes of aluminium and sometimes of wood; the rate at which they turn being about 150 r.p.m. Other forms of fan, such as that shown in the previous figure, usually rotate at much higher speeds.

Fig. 221 illustrates a *ship's ventilating fan,* this particular

type having been fitted on several of H.M. ships of war, as well as on other vessels. The motor, together with its switch and resistances, is completely enclosed and water-tight, as is essential for such work. The fan is started, controlled, or stopped by the handle on the right-hand side of the motor frame, and the leads enter through the stuffing boxes on the left. A portion of the commutator cover is removed, and part of the brush gear may be seen.

FIG. 219.—Table Fan (Drake and Gorham).

An ingenious method of gearing an electric motor to a punkah-puller is shown in Fig. 222. The enclosed motor at *M* drives through worm-gearing encased at *W*, a shaft at right angles with its own shaft. On this countershaft is mounted a *magnetic clutch K*. The part *F* is in the form of an annular iron-clad electro-magnet (Chap. *III.*), and is keyed to the shaft; while the armature *A* and rope pulley *P*, which are in one piece, are free to rotate upon the shaft. The clutch magnet coil is connected in series with the motor armature, through a 2-way switch *S′*, which in one position cuts out the coil and sets the rope pulley free. In the other position, the full current passes through the coil and holds

the pulley to the clutch. The switch is moved automatically, in time with the swing of the punkah, by toothed-wheel gearing at *G*. Two adjustable pins are fixed to the larger toothed-wheel, and these alternately catch the switch-arm and throw it over to "on" and "off." The length of rope and position of the pins are so adjusted, that when the punkah is at the bottom of its swing, the switch is put "on." The motor then winds up the rope until the punkah reaches the top of its swing, when the second pin throws the switch-arm over to "off," the clutch releases, and the weight of the punkah unwinds the rope from the pulley, and turns the toothed-wheel until the first pin comes into contact with the switch-arm, and puts it "on" once more. The motor as well as the clutch magnet are constantly running, but the speed of the latter is relatively low because of the worm-gearing. Contact with the rotating magnet *F* is made through brushes and slip-rings, one of the brushes being seen at *B*. *S* is the motor-starting and controlling switch.

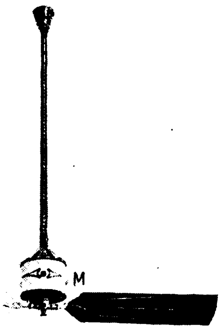


FIG. 220.—Ceiling Fan (Crompton and Co.).

An electric *overhead conveyer* is depicted in Fig. 223. The machine runs on rails suspended from the roof of the building, and the goods truck or other load is picked up and lowered at any desired points along the runway. A

FIG. 221.—Ship's Fan (Laurence, Scott, and Co.).

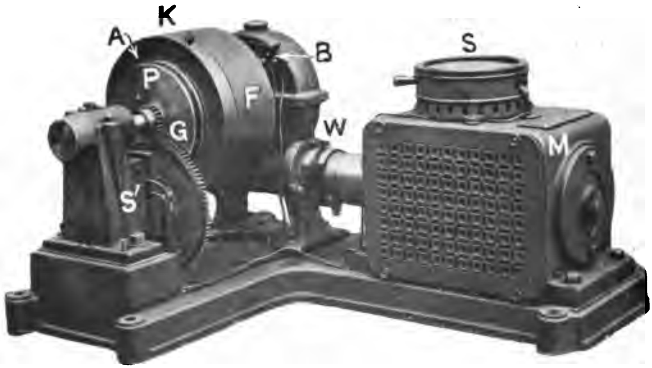


FIG. 222.—Punkah-Puller (Mavor and Coulson).

single motor fulfils the double duty of raising or lowering the truck, and of conveying it from point to point. The operator seats himself as shown, and travels about with the conveyer.

Fig. 223.—Overhead Conveyer (Mather and Platt).

In Fig. 224 we have an *electric travelling crane*, or *overhead traveller* as it is sometimes called. The movable double cross-girder runs on rails on opposite walls of, and reaching from end to end of the workshop or "bay." This movement of the whole is effected by an electric motor mounted at the near end of the girder. The *cross-traveller* moves to any

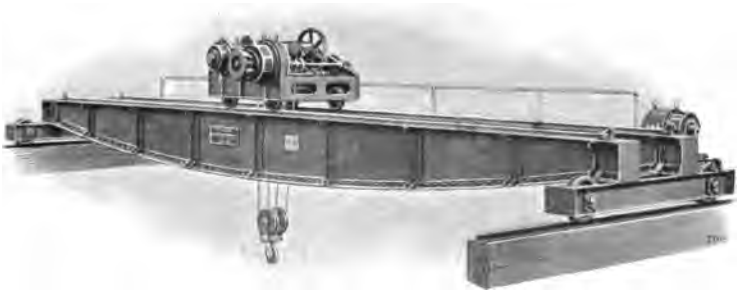


Fig. 224.—Travelling Crane (Crompton and Co.).

desired point along the girder, and then raises some piece

of machinery or other weighty mass from the floor level, and lowers it at any other desired point.

A peculiar form of crane, known as an *electric walking*

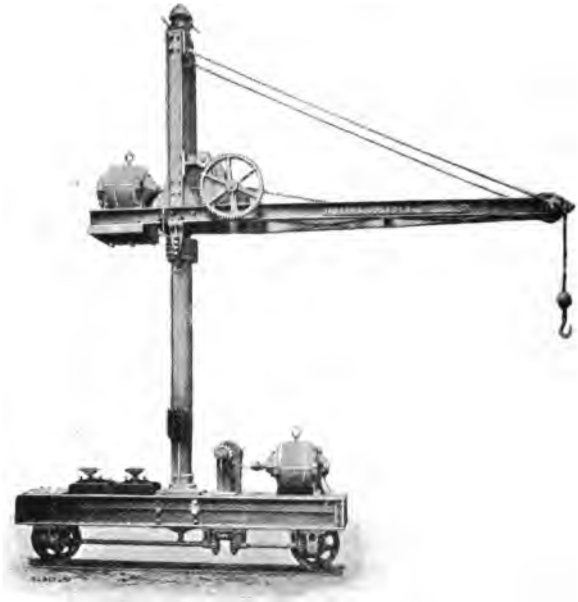


FIG. 225.—" Walking " Crane (Jessop and Appleby Bros.).

crane, is illustrated in Fig. 225. This runs on a single rail at the bottom, and is held upright by a roller at the top of the post, this roller working between two guide rails (not shown) supported by beams overhead. The motor on the truck works the travelling gear, while that on the

cross-girder or jib above, rotates the latter about the vertical pole, and then raises or lowers the lifting tackle.

Fig. 226 shows a semi-enclosed motor driving a horizontal pump through special gearing. The outside of the motor case is ribbed to assist in dissipating the heat; this construction being especially useful when

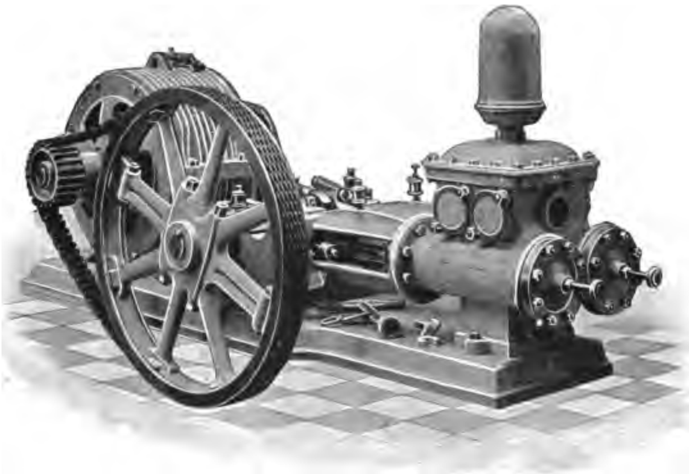


FIG. 226.—Motor-driven Pump (Mather and Platt).

the motor has to run for long periods, or is wholly enclosed.

Fig. 227 depicts a coal-cutter driven by polyphase motors, the whole being mounted on a truck running on rails. At the left-hand end of the truck is the starting switch. The motors drive on to the pinion which can be seen projecting at the side of the truck, and this gears into and drives the circular cutter. The motors are

generally of 10 B.H.P. each; and are reversible, the cutter running in either direction.

With the exception of those in Fig. 227, the motors shown in this paragraph all happen to be direct-current ones; but the mechanical gearing of alternating-current motors to machines would be exactly the same (§§ 135 to 138).

For the working of printing and other machines where a very large starting torque is required, where starting and stopping are of frequent occurrence, and especially where "inching-round" to certain positions is necessary, the

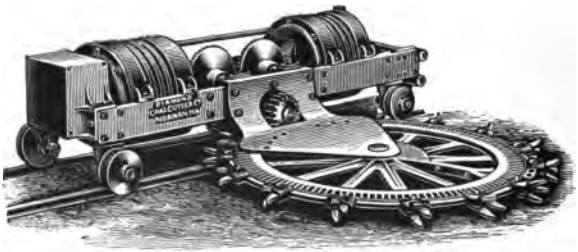


FIG. 227.—Electric Coal-Cutter (Bruce, Peebles and Co., and the Diamond Coal-Cutter Co.).

arrangement of main and auxiliary motors illustrated in Fig. 227A, which is known as the *Holmes-Clatworthy system*, has been devised. By "inching-round" is meant a spasmodic and intermittent application of the driving power, in order to work certain parts of the driven machine round to definite positions, for adjusting the work, and so forth. The main and auxiliary motors M and A are mounted on a common bed-plate, with their shafts at right angles with each other, and connected through worm-gearing W. The spur-wheel S on the main shaft

gears with the machine to be driven, the main shaft being divided by a clutch *C*, which is operated electro-magnetically. The smaller motor performs the starting or "inching-round," and this it does very effectively and without shock, by reason of the worm-gearing. It is only when a fair speed has been got up that the large motor is switched into circuit, so that it need not be of so great an output or such heavy construction as would otherwise be necessary.

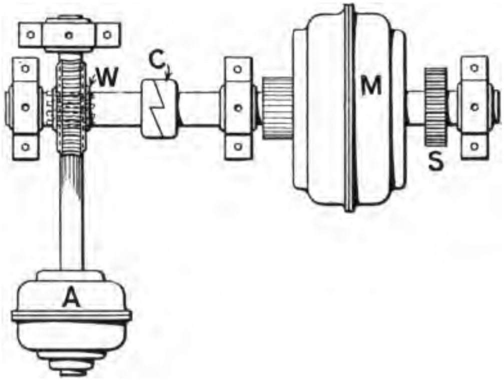


FIG. 227A.—Holmes-Clatworthy Motor System (J. H. Holmes and Co.).

The figure only shows the arrangement in outline, the electro-magnetic device operating the clutch *C*, and various other details being omitted. A special starting switch or controller is used, which first causes the clutch to engage, and then starts the auxiliary motor at its lowest speed. Further movement of the starter accelerates the speed of the small motor, and also gradually switches on a current to the main motor. When the shaft and armature of this main motor have acquired a good speed the machine

takes up the full load, the clutch is released, and the small motor cut out of circuit.

135. ALTERNATING-CURRENT MOTORS.—If the current from one direct-current dynamo be led into another dynamo, the latter will act as a direct-current motor. Similarly, if the current from a single-phase alternator be passed through a similar alternator, which has been previously run up to exactly the same speed, the latter will act as an alternating-current motor. In this case, however, the arrangement is not generally convenient; inasmuch as the F.Ms. of the alternator used as a motor, as well as of that used as a generator, have usually to be separately excited with direct current; and the two machines so connected must correspond with each other in frequency, and in other particulars. There is also a difficulty in starting; and if the motor is overloaded, it is liable to stop dead.

If two similar polyphase alternators be connected together, and one of them be driven as a generator; the second will run as a motor, if the current from the armature of the former be led round the field coils of the latter. Such a motor may be arranged to be self-starting. In this case, as well as with the above-mentioned combination of two single-phase alternators, the motor will run in synchronism with the generator, *i. e.* at a speed exactly corresponding with that of the generator: and this constant speed will be maintained under all normal conditions of load, which is a considerable advantage under certain conditions. Hence such motors are termed *synchronous motors.* A form of synchronous motor is used in the Ferranti Rectifier, which is described in § 207.

Asynchronous or *non-synchronous* motors are those whose speed is independent of the frequency of the driving current, and such may be constructed for either monophase or polyphase currents. The moving part, generally termed the *rotor*, need have no slip-rings or commutator; that is to say, there need be no electrical connection whatever with the outside circuit, the rotor being rotated by the oscillating or rotating magnetic field set up by the fixed portion, or *stator*. Thus such motors are frequently termed *induction motors*, and they are naturally of much greater general use than synchronous motors.

In some monophase asynchronous motors, the field is rather oscillatory than rotary; whereas in others and in polyphase machines it is purely rotary, this difference rendering the latter type of machine more efficient. In other words, the "torque impulses," so to speak, are more regular with polyphase than with monophase motors. Furthermore, some monophase motors suffer from the disadvantage that they will not start under load.

The terms rotor and stator are used to avoid ambiguity, as it is a matter for question as to which part could rightly be called the armature and which the field magnet. In a direct-current motor the armature is the moving part, and through this, according as it is series- or shunt-wound, the whole or the greater part of the driving current passes. In an induction motor, on the other hand, the whole of the driving current passes through the stator, and some would argue that this was consequently the armature.

136. Rotating Fields.—We know that in any kind of dynamo considerable power is absorbed in turning the armature or rotor through the field. If the part that is

usually fixed were mounted so that it were free to turn about the same axis as the rotor, it would follow the latter in its rotation.

Consider, for example, a simple 4-pole direct-current machine, and suppose that the field-frame were capable of rotation concentrically with the armature, the field windings being energized from some independent source through brushes and slip-rings. Then, when the armature was mechanically driven, the magnetic drag would gradually set the field-frame in motion, until at length its speed of rotation would be considerable. If the armature were connected-up through an external circuit, it would be found that very little pressure or power was being generated; for obviously there would be very little cutting of the lines of force of the field; nearly all the mechanical power taken from the engine, being employed, through the medium of the magnetic drag, in rotating the field-frame. Furthermore, it would be found that the rotation of the latter would be more effective if the commutator brushes were short-circuited; or if the segments of the commutator itself were short-circuited, say by tightly winding a layer of bare copper wire round the commutator.

After what has just been said, it is easy to understand that if the short-circuited armature were belted or otherwise geared to a machine, and the field-frame were rotated by means of an engine, the armature would revolve in consequence of its being in a rotary field, and would drive the machine.

The above furnishes the key to the action of a polyphase induction motor, wherein there is a *rotary* field with a *fixed* field-frame or stator. The rotation of the field is

brought about by the polyphase current; and the rotor is comparable with a direct-current armature from which the commutator has been removed, and the free ends of the windings all connected together. The rotor might be simply a conducting cylinder, but by having conducting strips or "windings," the induced currents are confined to well-defined paths, and the torque is the greater. Such is termed a *squirrel cage* rotor.

137. SPLIT-PHASE ROTATING FIELD.—A rotating field may be obtained from an ordinary monophase current by what is termed *splitting the phase.*

It was shown in Chap. *IV.* that it takes time to set up a current in a circuit, chiefly because of the inductance therein. When an alternating P.D. of sine-wave form is impressed on a circuit possessing resistance and inductance, the maximum value of the current is not reached at the same instant as the maximum value of the P.D., but lags behind the latter (Fig. 62). The time elapsing between these two maximum values, is directly proportional to the inductance of the circuit, and inversely proportional to its resistance. If we divide the inductance by the resistance the quotient will represent the *time-constant* of the circuit, or:—

$$\text{Time-constant} = \frac{\text{Inductance}}{\text{Resistance}}$$

Thus the greater the time-constant, the greater will be the lag of the current.

Now, referring to the 4-pole magnet in Fig. 228, it will be clear that if the two windings A and A', joined up in parallel to the supply-mains, were equal in resistance and ampere turns, and if the pole-cores were equal in size,

the time-constants of the two circuits would also be equal; and the field due to the four poles would be stationary, though alternating. If, however, we introduce a non-inductive resistance *R* into, say, *A* circuit, we shall decrease its time-constant, and the current in *A′* circuit, and consequently the field due to the poles 2 and 4, will lag behind the field due to the poles 1 and 3. In other words we shall have split the phase of the current. If the time-constant of *A* circuit be sufficiently reduced, the field due to 2 and 4 will lag about 45° behind that due to 1 and 3.

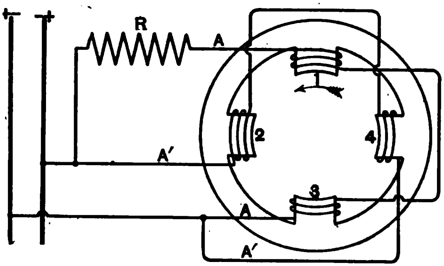


FIG. 228.—Split-phase Rotating Field.

In each period (§ 43), therefore, we shall have the following round of changes :—

ONE PERIOD.

Part of Period.	0°	45°	180°	225°
Circuit.	*A*.	*A′*.	*A*.	*A′*
Poles.	1—3.	2—4.	3—1.	4—2.
Polarity.	N. S.	N. S.	N. S.	N. S.

The field in the armature space will then be practically similar to what we should have got, had we taken a two-

pole direct-current field, and rotated it in the direction shown by the curved arrow; for poles 1, 2, 3 and 4 will be of north polarity one after the other, the corresponding opposite poles 3, 4, 1 and 2 being south in their turn; and the field rotation will be counter-clockwise. As the A' circuit current only lags 45° (or one-eighth of a period) behind the A circuit current, the rotation will not be uniform; the field passing more quickly between poles 1 and 2 and between 3 and 4, than between 2 and 3 and between 4 and 1. For this reason the winding has to be specially arranged in order to render the field rotation uniform. A squirrel-cage armature, such as was defined in the preceding paragraph, and is described in the following one, would revolve in such a rotary field.

The Shallenberger and Westinghouse meters (§§ 86 and 87) afford excellent examples of split-phase induction motors, the aluminium disks representing the rotor. In the description of these meters, it is explained that the rotation of the field is produced by placing one of the fixed coils at an angle with the other, and causing the current in it to lag behind the current in the other coil. As the pressure circuit of the meter has necessarily a high resistance, and consequently a smaller time-constant than the low resistance main circuit, the necessary conditions for splitting the phase already exist.

Phase-splitting of a single-phase alternating current in two parallel circuits, may also be produced by inserting a condenser in series with one of them, or if the two circuits or windings are connected in series, by shunting one of them by either a condenser or a non-inductive resistance.

Although it is evidently possible to construct a motor

on the principle shown in Fig. 228, it would not be economically practicable to do so; for the simple reason that the constant presence in the circuit of the non-inductive resistance R, would lead to a great waste of energy; and the motor would be very inefficient. The principle, however, is used for starting purposes only, in the Langdon-Davies single-phase motor, as described in the next paragraph; though the arrangement of the stator and its winding is different from the illustrative case given in Fig. 228.

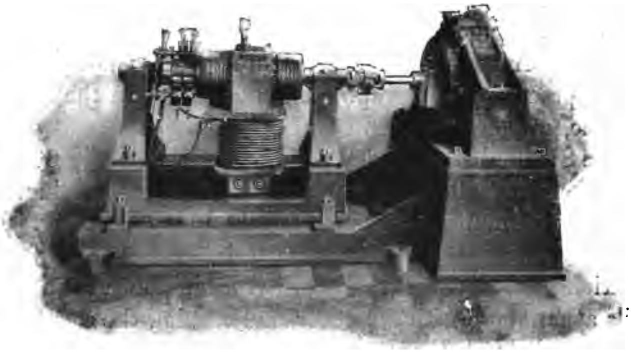


FIG. 229.—Langdon-Davies Motor coupled to Dynamo.

138. LANGDON-DAVIES SINGLE-PHASE MOTOR.—The external appearance of this machine will be gathered from Fig. 229, where it is shown coupled direct to a direct-current dynamo; the combination forming a motor-generator for the conversion of single-phase alternating into direct current (§ 205).

The rotor of this type of motor is depicted in Fig. 230, and it may be described as similar to a ring-wound arma-

ture, except that each coil is short-circuited on itself, and is not connected with its neighbours. This construction has been substituted for that of the ordinary *squirrel-cage*, in which the "windings" consist of a number of conductor bars placed in the rotor slots, and connected together at each end of the rotor by being soldered into conducting-rings. Referring to the figure, it will be noticed that the slots in which the windings are embedded are cut "on the skew." In the particular conditions under which the rotor works, this construction has been found to give a more uniform torque; and is expressively termed *staggered slotting* or *staggered winding*.

FIG. 230.—Rotor of Langdon-Davies Motor.

The stator, with the rotor removed, is illustrated in Fig. 231. The core is built up of a number of soft-iron stampings of the form shown in Fig. 232, in which it will be noticed that the slots are closed, so that the stator is tunnel-wound. This core is let into the outer cast-iron frame, and is fixed in place by a running of type metal. In all but the larger sizes, the stator is wound with four coils, which virtually form two circuit windings at right angles with each other. Two of the coils are "running coils," and two "starting coils"; and four poles are produced when current is flowing round the four coils. Each coil is wound

spirally, as shown in Fig. 233, which represents a portion of the stator core flattened out, and with open slots instead of tunnels to enable the winding to be seen. It will be observed that, starting from *A*, the winding passes successively through slots 1, 18, 2, 17, 3, 16, and so on; the last turn passing through slot 10 to *a*. The figure shows only one turn in each slot, but in reality there are several. It will be noticed that in Fig. 232, which shows an ordinary size of core-plate, there are 36 slots.

FIG. 231.—Stator of Langdon-Davies Motor.

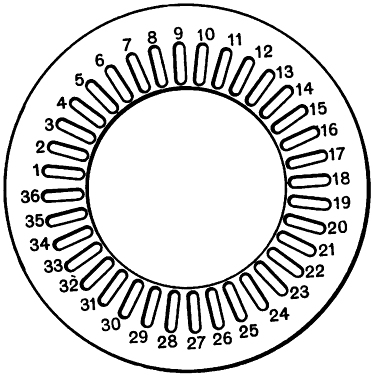


FIG. 232.—Stator Core Disk of Langdon-Davies Motor.

The two circuit-windings may be represented diagrammatically as in Fig. 234, which is similar to Fig. 228, so far as the disposition of the circuits is concerned, and is similarly lettered. Unlike Fig. 228, however, the windings intermingle, parts of neighbouring coils being wound

in the same slots. Thus referring to Fig. 232, if coil 1

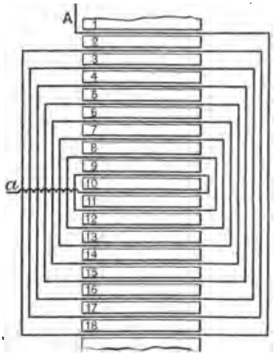


FIG. 233.—Spiral Winding.

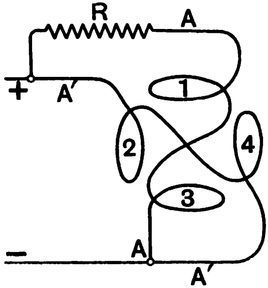


FIG. 234.—Diagram of Windings (Langdon-Davies Motor).

(Fig. 234) is wound in slots 1, 18, 2, 17, 3, 16, and so on as in Fig. 233, and coil 3 in numbers 36, 19, 35, 20, 34, 21, etc.; coil 2 would be distributed in slots 9, 28, 8, 29, 7, 30, 6, 31, etc., and coil 4 in numbers 10, 27, 11, 26, 12, 25, 13, 24, and so on.

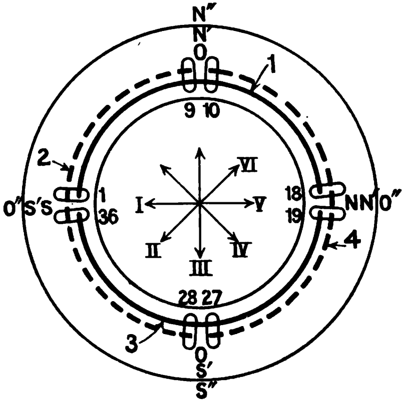


FIG. 235.—Illustrating the Action of the Langdon-Davies Motor.

Fig. 235 depicts a core-plate showing slots numbers 1, 9, 10, 18, 19, 27, 28, and 36, and the outer turns of the four coils; coils 1 and 3 being shown in firm, and coils 2

and 4 in dotted lines. With the help of Fig. 236, we will now endeavour to show how the rotation of the field takes place when current is switched on to the motor. The firm line curve represents the alternation of the field due to coils 1 and 3 in circuit *A*, and the dotted curve that due to coils 2 and 4 in circuit *A′* (Fig. 234). Those portions of the curves above the horizontal line denote N polarity, and those below denote S polarity. At position 1 on the curve, circuit *A* (coils 1 and 3) will have no polarity, this being indicated by *O*, *O* at the end of the vertical axis (Fig. 235). Circuit *A′*, on the other hand, will have maximum polarity, coil 4 being, say N, and coil 2 consequently S, as marked at the ends of the horizontal axis; and the direction of the field will be as indicated by the arrow-head I. At position 2 on the curve, coil 2 in circuit *A′* will still be S, and coil 1 in circuit *A* will be N; while coils or poles 4 and 3 will therefore be N and S respectively. This is indicated on the diagram by the letters *S′*, *N′*, *S′*, *N′*, and it will be obvious that the resultant field, now due to consequent poles, will be in the direction of arrow-head II. At position 3 on the curve, circuit *A′*, *i. e.* coils 2 and 4, will be inactive; while circuit *A* will have full polarity, coil 1 being still N and coil 3 S; this condition of things being indicated by *O″*, *O″*, *N″*, and *S″*.

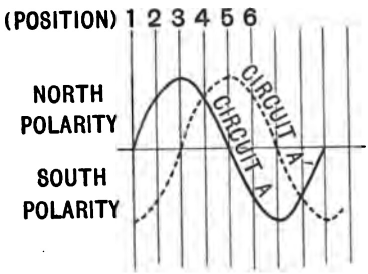


FIG. 236.

The field will then be in the direction of arrow-head III. Similarly it may be shown that position 4 on the curves gives N poles at 1 and 2, and S poles at 3 and 4, producing a resultant field as indicated by arrow-head IV. In like manner the polarities for positions 5 and 6 are indicated by arrow-heads V. and VI., and so on. The field consequently rotates in a counter-clockwise direction.

The starting coils (2 and 4) and the running coils (1 and 3) are joined up to three terminals on the top of the motor

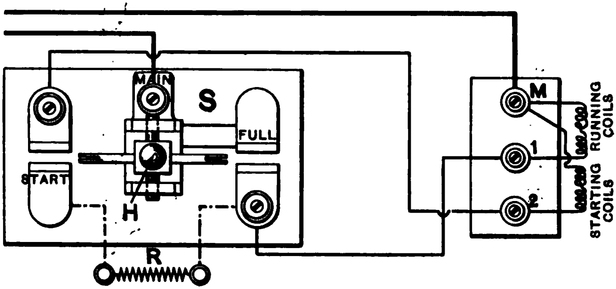


Fig. 237.—Starting Switch of Langdon-Davies Motor.

(Fig. 229). As shown in Fig. 237, these terminals are marked *M*, 1, 2; and are connected through a two-way switch *S* (which also has an "off" position) with the supply circuit, and with a non-inductive resistance *R* which corresponds with *R* in Figs. 228 and 234. The switch is drawn in its "off" position. To start the motor, the handle *H* is first thrown over to the left, thus connecting *R* in series with the running coils; and the circuit conditions are then exactly as in Fig. 228. The rotary field set up starts the motor, and when a good speed has been attained, the switch is thrown over to the right, thereby cutting out the

starting coils and the resistance R, and leaving what is merely a 2-pole monophase field.

It now remains to give some simple explanation as to how the rotor, when once set well in motion, continues to rotate. Firstly it is a fact that the direction of rotation depends simply on the direction in which the motor is started. Thus if the connections of the ends of the starting or A' circuit in Fig. 234 were reversed, the starting field would rotate in a clockwise direction. The rotor would consequently start in that direction, and would continue to rotate the same way after the starting circuit had been cut out. It is also a fact that a simple alternating field, such as would be set up by circuit A alone, if the rotor were at rest or were removed, is mathematically equivalent to two fields of equal strength rotating in opposite directions. Now it is conceivable that when the rotor is started, in, say, a counter-clockwise direction, it gives a bias to the field in that direction; or, in other words, it encourages most of the field to rotate that way also, the rotating core producing this effect since it forms a considerable part of the magnetic circuit. There is no forcing in this matter, for the motor has to receive, not give out electrical energy. The flux of magnetic lines which passes through the rotor, which, because of the alternating exciting current in the stator, alternates in polarity at each pole, may, when the rotor is at rest, move round the core in either or both directions. When the inner part of the core, *i.e.* the rotor, is in rotation, the flux may be supposed to find it most convenient to travel in the same direction as the rotor.

Another and more accurate, though less simple explan-

ation is as follows. Assume that, by phase-splitting or some other means, the rotor has been started in a counter-clockwise direction, and run up to a speed of n revs. per sec. Then, any additional fields employed for starting purposes having been removed, the rotor will be revolving, at a speed of n revs. per sec., in a simple alternating field due to the monophase current of the supply. This stationary alternating field may be decomposed into two equal alternating fields rotating in opposite directions, and having their maximum values equal to half the maximum value of the resultant stationary field. Suppose the speed of rotation of these two components is n_1 revs. per sec. Then the slip of the rotor with respect to the component rotating in the same direction (counter-clockwise) as the rotor will be $n_1 - n$; but the slip with respect to the component rotating in the clockwise direction will be $n + n_1$ (§ 141).

In consequence of the slip in the latter case being so very large, the phase of the clockwise rotating field will be almost opposite to that of the field set up by the rotor. Their resultant, and hence also the backward torque exerted by the clockwise rotating field, will therefore be very small. The forward torque due to the other component is, however, considerable, owing to the small value of the slip $n_1 - n$. The rotor will therefore continue to revolve in a counter-clockwise direction, and the stationary simple alternating field will act virtually as a field rotating in one direction only.

From the above explanation it is easy to see why the motor will not start from rest if the stator be excited by a simple monophase current. For then n, the speed of the rotor $= o$, and the values of the slip with respect to the

two rotary component fields are equal, viz. n_1. Hence the torques exerted by the two components are also equal, and as they are opposite, the rotor will not revolve.

138A. HEYLAND SINGLE-PHASE MOTOR.—This is one of the latest developments of the single-phase non-synchronous motor, and it possesses the considerable advantage of being able to start under full load. This compensates for the disadvantage of having to use slip-rings and a starting resistance in the rotor circuit; and for the fact that for a given output the machine is larger and

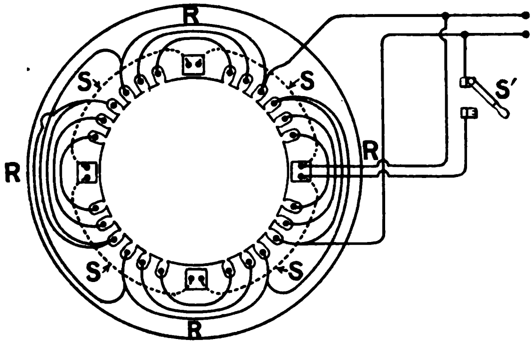


FIG. 237A.—Stator Windings of Heyland Motor.

heavier than that described in the preceding paragraph. As in the Langdon-Davies motor, the stator is wound with starting and running coils, which, however, are in this case joined straight up to the supply mains, without the interposition of any external resistance. The phase is split by making the starting winding with less resistance and greater inductance than the running winding: and the starting field is greater than the running field, which is the main reason of the large starting torque obtained.

The running coils are wound in very much the same spiral manner as in the Langdon-Davies motor, except that there are generally four or more poles. The starting coils, on the other hand, though corresponding in number with the running coils, are each wound through two tunnels or closed slots, these coils having their axes midway between those of the running coils. This arrangement will be understood from Fig. 237A, where *S, S, S, S* are the four starting coils, and *R, R, R, R* the four running coils, the

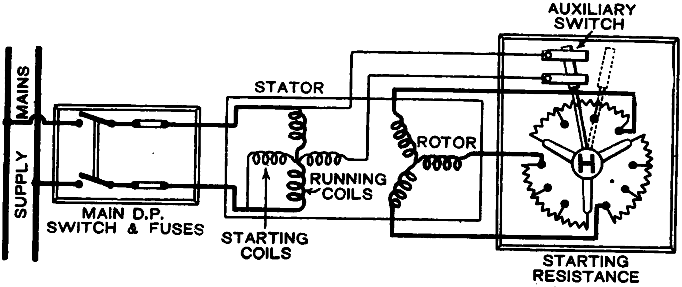


FIG. 237B.—Circuit Connections of Heyland Motor.

starting circuit being governed by a switch *S′*. When once started, the action is practically the same as that of the motor described in § 138. The circuit connections are given in Fig. 237B. The motor terminals are joined straight up to the supply mains through a D.P. switch and fuse. The auxiliary switch in the starting-coil circuit (*S′* in Fig. 237A) is combined with the handle *H* of the 3-circuit starting resistance, in such a way that, when the motor has been started, the movement of *H* in order to cut out the resistance in the rotor circuit at the same time puts the auxiliary switch "off." The reason for the starting resistance in the rotor circuit is explained in § 140.

FIG. 237C.—Parts of Heyland Motor (Witting, Eborall & Co.).

The parts of the machine are shown in Fig. 237c. From this it will be seen that the stator core with its winding is let into an outer circular cast-iron frame; the end covers of which carry the bearings, which are fitted with oil wells and ring lubricators. On the right of the figure is the rotor, with the three ends of its winding protruding from the further end of its shaft. By the side of this are the brush-holders and brushes, while in front of the stator the rotor slip-rings may be seen.

139. Rotation of Polyphase Fields.—The rotation of a 2-phase field will be understood from Fig. 238. This represents a 4-pole magnet, the windings of poles 1 and 3 being connected in phase *A* circuit; and those of poles 2 and 4, in phase *B* circuit. After what was said in § 61, it will be remembered that the current in phase *B* lags 90° or a quarter-period behind the current in phase *A*. If, to start with, pole 1 be N and pole 3 be S, the changes during a whole period or cycle will be as follows:—

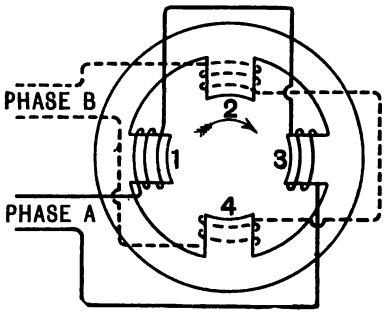


Fig. 238.—Rotation of a 2-phase Field.

ONE PERIOD.

	1st quarter.	2nd quarter.	3rd quarter.	4th quarter.
Phase.	*A.*	*B.*	*A.*	*B.*
Poles.	1—3.	2—4.	3—1.	4—2.
Polarity.	N. S.	N. S.	N. S.	N. S.

The rotation of the N and S polarity, *i.e.* of the field, is clockwise; and is practically similar to what would have happened had we taken an ordinary direct-current 2-pole field, and rotated it at the same rate.

Fig. 239 illustrates the rotation of a 3-phase field. In order to get a uniformly rotating field, it is necessary so to dispose the phase-windings that, following round the pole-circle in the *direction of rotation*, the phases run *A C B*, not *A B C*. Thus poles 1 and 4 are connected in series to phase *A*, 2 and 5 in series to phase *C*, and 3 and 6 in series to phase *B*. The different phase-windings are differently lined, and it should be noted that they have a common return wire, though this, by the way, is not absolutely necessary. It was explained in § 61 that the phases of the three currents differ from each other by one-third of a period or cycle. Each of the phase-windings will therefore set up a field between its poles, which at any instant will differ, both in direction and magnitude, from the fields set up by the other phase-windings. Consequently, the three phase-windings acting together will produce a resultant field; and if we plotted out the directions of this field for various fractions of the period, we should find that in one complete period the resultant field made one complete round of the poles, and that it rotated in the clockwise direction, as indicated by the curved arrow.[1] The positions of the resultant field during one complete period may be tabulated as follows :—

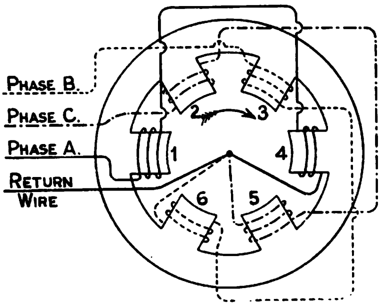


FIG. 239.—Rotation of a 3-phase Field.

ONE PERIOD.

Fraction of Period.	1st. $\frac{1}{6}$	2nd. $\frac{1}{6}$	3rd. $\frac{1}{6}$	4th. $\frac{1}{6}$	5th. $\frac{1}{6}$	6th. $\frac{1}{6}$
Poles.	1—4.	2—5.	3—6.	4—1.	5—2.	6—3.
Polarity.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.

[1] See the Second Edition of the Author's *Alternating-Current Circuit*.

This cycle of pole changes, as was the case with the 2-phase field, is practically equivalent to rotating a direct-current 2-pole field at the same rate.

140. Starting of Polyphase Motors.—It has been stated that the rotor of an induction motor need have no connection whatever with the outside circuit. Such is indeed the case when the motor does not have to start under much load. Otherwise, *i. e.* where considerable starting torque is required, it is usually necessary to provide slip-rings and brushes, in order that a rheostat or variable resistance may be joined up with the windings of the rotor. Such resistance is generally used only at starting, and is either short-circuited or disconnected during the running of the motor. By leaving more or less of it in the rotor circuit, the speed of the motor may be varied.

As the rotating field cuts the rotor, E.M.Fs.—and hence currents—are generated in the windings of the latter, in exactly the same way, and with the same effect, as if it were the armature of a dynamo: the E.M.F. being reversed in each individual coil or conductor as many times as the field adjacent to it changes in polarity. Now, when a current is set up in a coil, it takes time to die away before a reverse current can flow, especially when the coil has appreciable inductance. Thus it is conceivable that, when the field is rotating round a *stationary* rotor, the induced currents in the latter may be so confused that the tendency to turn (torque) is very small, and quite insufficient to start the rotor if the motor be "loaded." For though the rotation of the rotor depends primarily on the rotation of the field; it also depends upon the induction and reversal of currents in the rotor windings taking place in a definite

order. This effect, *i. e.* the inability of the rotor to revolve, is the more marked the higher the frequency; for on the latter depends the rate at which the field will rotate (§ 141). This is one of the reasons why low frequencies are habitually employed in polyphase work.

The confusion of induced currents in a stationary rotor, when the field is cutting it at a high speed; and its uncertainty in starting, especially under load; may be rendered clearer by considering the converse case. Thus, if we had a direct-current dynamo with its field already fully excited, and a very low resistance (*i. e.* a potential heavy load) connected to the armature; it is quite probable that if we started the machine *immediately* at a high speed, the electromotive-forces and currents set up in the various coils, would be so confused in direction, that the electrical output would be very small. Such a state of things never occurs in practice, however, for the simple reason that the field of a self-exciting dynamo takes time to "grow"; and even if it be separately excited, the armature can never be made to start at full speed.

The interposition of resistance in the rotor circuit, in the manner explained at the beginning of this paragraph, reduces the strength of the currents induced in the rotor windings, and also the time-constant of the latter. It may then be assumed that these currents take up their proper order of induction with much greater ease, and thus enable a good starting torque to be exerted.

It is evident that if the frequency could be slowed down at starting, all this difficulty, and the necessity for external resistances in the rotor circuit would be removed. But this would be impossible unless the power supply came from

one's own polyphase generator; and even if it did, the slowing down of the generator every time a motor had to be started would be very impracticable, especially when there were other motors at work, as would generally be the case.

There is, however, another way in which the starting difficulty may be got over, and that is by placing a choking coil in each phase circuit of the field, so that the strength of the field, and of the rotor currents induced by it, may be made small to start with. The "induction confusion" (as we may term it) in the rotor is thereby lessened, and the latter is enabled to start without difficulty.

141. FREQUENCY, SLIP, AND SPEED.—The more rapid the rotation of the field, the greater is the starting difficulty with motors; and it is on this account that there is a tendency to use as low a frequency as possible for power work. On the other hand, the frequency must not be too low, or else it would not be possible to use the same supply for incandescent lighting; the rise and fall of the current in the lamps being perceptible at very low frequencies. If p be the number of *pairs of poles per phase*, the number of revolutions (n) of the field per minute will be :—

$$n = \frac{60 \times \sim}{p}$$

When a polyphase motor is running, the rotor can never reach the same speed of rotation as the field, so that "racing" is unknown with this class of motor, a fact which constitutes one of its advantages. The field rotates round the rotor at a greater rate than the latter revolves, the difference in speed being known as the *slip*. The greater

the load the greater the slip. In other words, the slip is proportional to the load, *i. e.* to the torque.

The connection between the frequency, slip, and speed of a polyphase motor is shown by the following example :—

"*An induction motor is supplied with* 3-*phase current at a frequency of* 50 *periods per second. What speed will it run at if there are* 16 *pairs of poles per phase and the slip of the rotor is* 4 *per cent.?*"

As already shown (p. 425), if the rotor were rotating in synchronism with the field, as would be the case if there were no load on it and therefore no slip, its speed would be given by the formula :—

$$\text{Number of revs. per min.} = \frac{60 \times \sim}{p}$$

where $\sim$ is the frequency of the currents supplied, and p the number of pairs of poles per phase: $\sim$ being multiplied by 60 to get the frequency in periods per minute.

Now the slip of the rotor is the difference between its speed and that of the field, and in the case under consideration is 4 %.

Hence the actual speed of the rotor :—

$$= \frac{96}{100} \times \frac{60 \times \sim}{p}$$

$$= \frac{96}{100} \times \frac{60 \times 50}{16}$$

$$= 180 \text{ r. p. m.}$$

142. Reversal of Polyphase Motors.—To provide for the reversal of the direction of a 2-phase induction motor, it is only necessary to insert a reversing switch in the circuit of one phase, so that the connections of the pole windings therein may be reversed. Thus, referring to Fig.

238, with the windings as there shown, the polarities during one period, before and after the reversal of the 2-phase winding, would be :—

Phase.	*A.*	*B.*	*A.*	*B.*
Poles.	1—3.	2—4.	3—1.	4—2.
Before reversal.	N. S.	N. S.	N. S.	N. S.
After reversal.	N. S.	S. N.	N. S.	S. N.

Before reversal, the north polarity travels round to poles 1, 2, 3, and 4 in turn; that is to say, the rotation of the field is clockwise. After reversal, on the other hand, the north polarity travels round *viâ* poles 1, 4, 3, and 2, *i. e.* in a counter-clockwise direction. And since the direction of rotation of the rotor corresponds with that of the field, the reversal of the connections of the *B* circuit will thus effect the reversal of the motor.

With a 3-phase motor, two of the phase connections must be interchanged, and the connections of their field windings reversed. Thus if in Fig. 239 we change poles 2 and 5 over from phase *C* to phase *B*, and poles 3 and 6 from phase *B* to phase *C*; and at the same time reverse the connections of the field windings so as to reverse the polarities, we shall get a reversal of rotation. This will be clear from the following table :—

ONE PERIOD.

Fraction of period.	$\frac{1}{6}$	$\frac{2}{6}$	$\frac{3}{6}$	$\frac{4}{6}$	$\frac{5}{6}$	$\frac{6}{6}$
Poles.	1—4	2—5	3—6	4—1	5—2	6—3
Before change of connections.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
Poles.	1—4	6—3	5—2	4—1	3—6	2—5
After change of connections.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.

In the first case, as already shown, the north and south polarity (*i. e.* the field) travels round in a clockwise direc-

FIG. 240.—Unwound Stator of Polyphase Motor (Johnson and Phillips).

tion; but after the change of connections the field rotation will be counter-clockwise.

143. JOHNSON AND PHILLIPS' POLYPHASE MOTOR.—Polyphase motors differ widely in construction, arrange-

ment of windings, starting and controlling gear, and so forth; but it must suffice to mention two or three examples only.

Fig. 240 shows an unwound stator of a Johnson and

FIG. 241.—Stator wound for 2-phase work (Johnson and Phillips).

Phillips' motor. The core is a tunnelled one, and is built up of a number of core-plates clamped together by bolts between two stout metal plates which are attached to the cast-iron outer frame. Each tunnel is lined with a press-spahn insulating tube before the stator is wound; and the

protruding ends of these tubes will be noticed. The surface of the core shown in Fig. 240 is broken by narrow slots cut through into each tunnel; but these are now dispensed with, the core having a continuous surface as in Fig. 241, which depicts a stator wound for 2-phase work, with eight coils in each phase. The arrangement of a similar 2-phase winding, having six coils in each phase, is illustrated in Fig. 242. Here the firm line coils marked *A*, *A*, *A*, are those in phase *A*; while the outer set shown in dotted lines and marked *B*, *B*, *B*, are those in phase *B*. This figure should be compared with Fig. 241. In both it will be noticed that each set of coils is joined up to a separate pair of terminals, this being a 2-phase winding. Although from these two figures it would appear that the one set of coils was arranged behind the other, this is not really the case, for each coil has its separate slots, and the windings of the two phases are equally near to the rotor gap. This will be understood from Fig. 243, where *E* are the end turns or bends of one of the *A* coils, and *E'*, *E''* those of two adjacent *B* coils, the former

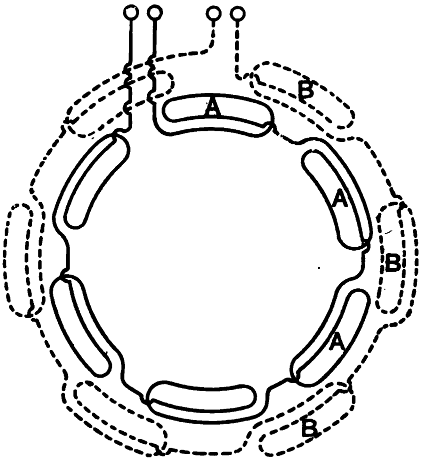


FIG. 242.—Diagram of Stator 2-phase Winding.

being drawn down to show the latter. As the *E* bends must of necessity stick straight out from the slots, *i. e.* lie in the same planes as the conductors in the slots (of which they form parts), so as to leave the rotor-gap free, as shown in Fig. 241; it follows that *E′*, *E″* and the other bends in the same phase must be turned back behind the bends of the "*A*" coils. A stator with a 3-phase winding would present the same general features as Fig. 241; except that there would be three series of coils, and three terminals only. This arrangement is diagrammatically given in Fig. 244, where *A*, *A*, *A* . . . , *B*, *B*, *B* . . ., and *C*, *C*, *C* . . . , are the coils of phases *A*, *B*, and *C* respectively One end of each series starts from one of the terminals *T*, *T*, *T*; while the inner ends of all three phases are connected

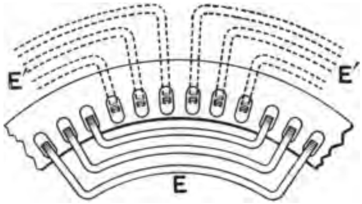


FIG. 243.—Disposition of Coil ends on Stator.

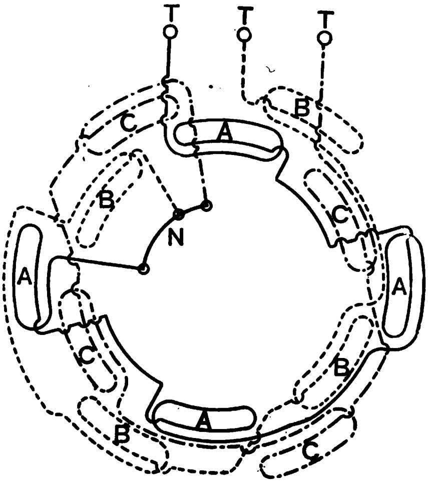


FIG. 244.—Diagram of Stator 3-phase Winding.

together by a neutral connector *N*; this being known as a

FIG. 245.—Unwound Rotor (Johnson and Phillips).

star-connected winding (Fig. 248). When the direction of

FIG. 246.—Wound Rotor (Johnson and Phillips).

the current in phase *A* is towards the neutral point *N* (Fig. 248), it may be presumed to return *viâ* the *B* and *C*

circuits; while the *B* and *C* currents may be said to return by the *C* and *A*, and *A* and *B* circuits respectively. Thus it will be seen that the return wire illustrated in Fig. 239 is not always necessary.

Fig. 245 shows the laminated iron core of a rotor mounted

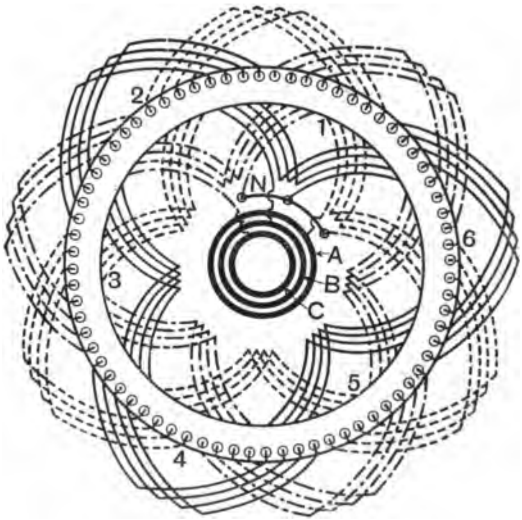


FIG. 247.—Wave Winding for Rotor.

on its shaft before being wound. The "winding" may consist of a number of bars placed in the slots, and connected at each end by a common conducting ring, to form a squirrel-cage (§§ 136, 138); or the core may be wound with coils connected to three collector rings, for use with an external starting resistance, as in Fig. 246. There are two or three methods of winding such a rotor, that generally

F F

adopted by Messrs. Johnson and Phillips, and known as a *wave winding,* being illustrated in Fig. 247; where the conductors are shown connected for 3-phase work. Starting from the collector ring *A*, one winding proceeds *viâ* core slots 1, 2, 3, 4, 5, 6, and so on, till it terminates at the neutral bar *N*. The other windings start respectively from rings *B* and *C*, and, proceeding in a similar manner, likewise terminate at *N*. Thus the rotor, like the 3-phase stator, is star-connected; as diagrammatically represented by Fig. 248, where *A*, *B*, and *C* are the three sets of windings, *N* the neutral connector, and *T*, *T*, *T*, the terminals in the case of the stator, or the slip-rings in the case of the rotor.

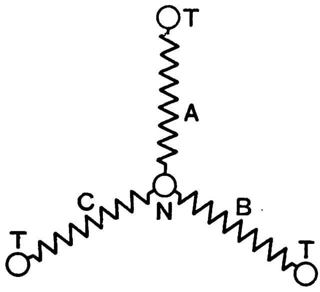


FIG. 248.—Star-connection.

Fig. 249 is a diagram of the *three-circuit rheostat* or starting resistance, and shows its connection to the brushes and slip-rings of a 3-phase rotor. The figure depicts the switch in the "off" position. To start the motor, current is first switched on to the stator, say by means of an ordinary triple-pole switch; and the rheostat handle is then turned in the direction of the curved arrow. When its arms reach the studs *S*, *S*, *S*, the rotor starts, all the resistance being then in circuit. As the arms are moved further round, the resistance is gradually cut out, until the last stops *L*, *L*, *L*, are reached, when the brushes and slip-rings are virtually short-circuited, and the motor exerts its greatest torque. In the

case of the Johnson and Phillips' machines, it is usual to keep the brushes down all the time the motor is running. In some motors, however, arrangements are made for short-circuiting the rotor rings, and raising the brushes, when the motor has been run up to speed; the starting resistance being then entirely disconnected. This is the case with the motors described in §§ 144 and 146.

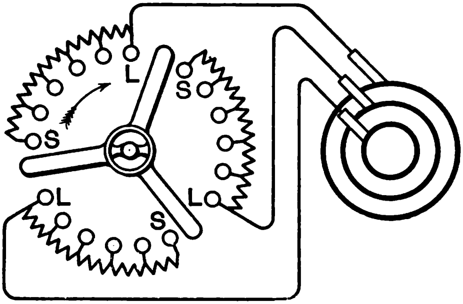


FIG. 249.—Starting Resistance for 3-phase Motor.

Fig 250 illustrates a 2-phase motor with squirrel-cage rotor; the common ring to which the bars are connected being clearly shown at *R*. This firm build motors with short-circuited rotors, in sizes ranging from ½ to 50 B.H.P.; and with slip-rings for starting resistances in sizes from 5 to 200 B.H.P. and upwards.

FIG. 250.—2-phase Motor with Squirrel-cage Rotor (Johnson and Phillips).

144. BRUCE PEEBLES AND CO.'S POLYPHASE MOTOR.—A complete 3-phase motor for sizes of 80 H.P. and upwards is illustrated in Fig. 251; and its novel appearance as compared with other machines,

is due to the fact that the rotor is hollow, and open at the sides.

FIG. 251.—Polyphase Motor (Bruce Peebles and Co.).

For these larger outputs, the rotor is provided with slip-rings, and brushes with multiple carbon contacts; these permitting the use of a starting resistance in the manner already described in the last paragraph. When the motor is fairly started, the slip-rings are short-circuited, and the brushes raised.

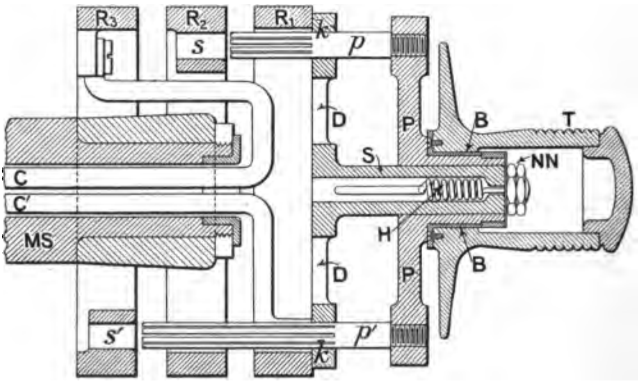


FIG. 251A.—Slip-Ring Short-circuiting Device (Bruce Peebles Motor).

The short-circuiting device is shown in Fig. 251A. Here

M S is the motor spindle, which is hollowed at this end to allow of the cables *C*, *C′* passing through. *C* is joined-up to the collector ring R_3, and *C′* to the ring R_1; R_2 being connected through the motor spindle with its end of the rotor winding. The method of supporting these rings may be seen in Fig. 251B. Here it will be observed that R_2 forms part of a casting *K*, which is driven on to the tapered end of *M S*, and secured by a nut *N*. The opening in the shaft is bushed with insulation *I*, to prevent contact between the end of the shaft and the ends of the cables, and possible abrasion of the latter. The rings R_1 and R_3 are fastened by three insulated bolts to R_2; one of these, shown at *B*, being insulated by the fibre bushes and washers, *F*, *F*. Returning to Fig. 251A, the ring R_1 carries a spider with three arms, two of which are represented by *D*, *D*. The centre of the spider supports a shaft *S*, on which slides a two-armed piece *P*,*P*, carrying two contact plugs *p*,*p′*, which are pushed in or pulled out by the teak-wood handle *T*. The latter, together with the slip-rings, can also be seen in Figs. 251 and 253. In the position shown (Fig. 251A), the rings are open-circuited, *p* and *p′* only making contact with R_1 as at *k*, *k*. *P* with *p* and *p′* is kept in this position by the tension of the helical spring *H*, in the hollow of the shaft *S*; one end of this spring being attached to *P*, while the other is fastened by the double nuts *N N*. When *T* and *P* are pushed inwards, *p* makes contact with the socket *s* on the inside of R_2, and *p′* with *s′* on R_3; and all three rings are

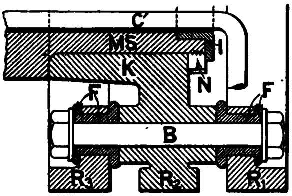


FIG. 251B.—Mounting of Slip-Rings on Shaft (Bruce Peebles Motor).

connected. *H* really only acts as a buffer spring, *p* and *p′* fitting "spring-tight" into *k*, *k*, *s* and *s′*. The handle *T* is bushed with brass at *B*, *B*, this forming a bearing on which the handle rides loose on *P*, *P*.

FIG. 252.—Wound Stator Frame (Bruce Peebles and Co.).

The stator-frame is removable from the outer frame, as will be seen in Fig. 252; the core being slotted, and the windings "former-wound." The rotor is wave-wound in slots, like that of the Johnson and Phillips motor (Fig. 247).

Fig. 253 depicts a rotor belonging to a smaller size of machine, and the simplicity of the arrangement of the slip-

FIG. 253.—Wound Rotor (Bruce Peebles and Co.).

rings and short-circuiting device will be noticed.

145. HARDING CHURTON AND CO.'S POLYPHASE

MOTOR.—Fig. 254 shows a motor, without slip-rings, which is very similar in general appearance to that in Fig. 250. With this make slip-rings are usually only fitted to those machines which are required to start at full load, and which exceed 6 horse-power. The bearings are of the self-oiling type, and the terminals are enclosed in a hard-wood case fitted on the side of the motor.

FIG. 254.—Polyphase Motor (Harding, Churton and Co.).

146. GENERAL ELECTRIC CO.'S 3-PHASE MOTOR.—The smaller motors made by this firm have a short-circuited rotor. In the large ones, the rotor windings, on starting, are joined-up, through slip-rings and brushes, with a three-circuit rheostat in the same manner as was illustrated in Fig. 249, and described in connection therewith.

Sometimes a slip-ring short-circuiting device is fitted to the motor, this enabling the brushes to be lifted, and the friction and wear thereat stopped, when the motor is once started. The machine shown in Fig. 255 is so fitted. When the lever opposite the end of the shaft is pulled outwards, the slip-rings are disconnected from each other; but when it is pushed inwards, they are short-circuited.

This lever is connected to a gun-metal ring which carries three copper tongues; and when it is pushed inwards, these tongues make contact with flat copper strips fitted on the inside of each of the slip-rings, thus short-circuiting the latter. A second lever (not seen in the illustration), having two arms of different length, is pivoted on the

FIG. 255.—3-phase Motor with Short-circuiting Device (Gen. Elec. Co.).

rocker. The longer arm carries a handle, while on the shorter one is mounted a pin passing horizontally beneath the three brushes. The lever may be fixed in two positions. In one, the pin does not touch the brushes, which then press on the slip-rings; while in the other, it lifts the

brushes clear of the rings. When the motor has started, the slip-ring short-circuiting lever must be operated first, and then the brush-lifting lever. The stator terminals, as will be seen, are mounted on the top of the motor.

*147. TRANSMISSION OF POWER.—Strictly speaking, every circuit in which current is being usefully employed—whether for motive, lighting, heating, chemical, signalling

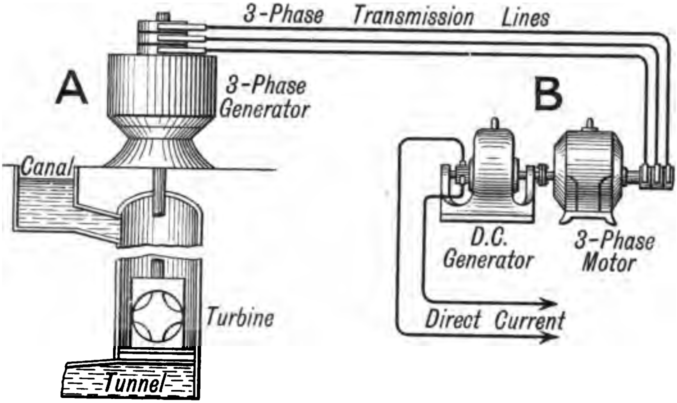


FIG. 256.—The Electric Transmission of Power.

or other purpose—presents a case of the electric transmission or distribution of power: but the term is more generally confined to those circuits in which the current is used for motive purposes only.

In the great majority of cases, motors are run off the constant-pressure public supply mains; but in isolated instances, and when much larger motors are employed, the latter are connected to special mains. Fig. 256 gives some idea of the wholesale transmission of power from one

place to another. *A* may be the location of water power, and *B* a place or town some distance away. At *A* is a turbine driving a polyphase generator, the current from which is delivered at high pressure to *B*, and there fed into a motor generator whereby it is converted into direct-current. The current after leaving the polyphase generator at *A* would usually be transformed up to a still higher pressure, and afterwards passed through a step-down transformer at *B*. The direct-current at *B* would then be distributed through a central-station switchboard. At *A*, two or more generators in parallel could feed into the transmission lines, which at *B* could supply a number of motor generators or transformers in parallel. The supply would not necessarily have to be converted into direct current. The figure, by the way, indicates a generator with a vertical shaft, this being a mode of construction specially suitable for turbine driving.

At the present time, huge generating stations are being built in various coal districts in England; and here polyphase currents at high pressure will be generated and distributed to surrounding towns and districts; where, by means of transformers, the supply will be converted to the ordinary pressure and character (direct or alternating) suitable for general use.

CHAPTER XIV.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Distinguish between a motor and a dynamo.

*2. Name the principal kinds of motor, and explain briefly their different features.

*3. Re-draw Fig. 171 I, illustrating the action of the shuttle-arma-

ture motor ; and complete the figure by the addition of an armature coil, field magnet, shunt field-coil, and driving battery.

*4. Explain concisely, in three ways, the action of the drum-armature motor.

*5. Sketch a simple 2-coil drum-armature motor, with field magnet, commutator and driving battery.

*6. Explain clearly, in your own words, the action of the ring-armature motor.

*7. Imagine you have a large powerful electro-magnet, such as might belong to a dynamo-machine, and with only a short gap between the poles, also that the magnet is excited so as to produce a very powerful field in the gap. Say what you know about the effect which would be produced on a conductor passing freely through the gap, when a current of 100 amps. was caused to flow through the conductor. [Prel. 1902.]

8. Give a simple rule for the direction and magnitude of the E.M.F. induced in a wire passing the face of a north-seeking pole, and for the force exerted on it per ampere. [Ord. 1899.]

9. A straight wire carrying a continuous current of 500 amperes lies at right angles to the magnetic flux in a field the intensity of which is 10,000 lines per square centimetre. State the force, in pounds, per foot of the wire tending to produce lateral displacement. [Ord. 1894.]

10. Explain fully, by the help of sketches, why a shunt-wound dynamo runs in the same direction whether it is used as a motor or as a generator, supposing that the current supplied to it when working as a motor enters by the same brush as that at which the current comes out of it when used as a generator. [Ord. 1890.]

*11. Explain how it is that the back E.M.F. of a motor opposes the working E.M.F.

*12. The power absorbed by a motor is proportional to its load. Elucidate this statement in your own words.

*13. In connecting up a shunt dynamo to run as a motor, would you join the positive pole of the circuit to the positive or negative terminal of the machine? Give full reasons for your answer. [Prel. 1898.]

*14. How many volts are needed to send a current of 20 amperes through a conductor having 10 ohms resistance? What difference would it make in your answer if the circuit included a motor having a back E.M.F. of 450 volts? [Prel. 1896.]

15. A series dynamo has an armature resistance of 0·4 ohm, and a field resistance of 0·6 ; and gives 120 terminal volts at a given speed and current of 10 amperes: work out its electrical efficiency as a dynamo and as motor at that speed and current. [Ord. 1895.]

16. Why must a forward lead be given to the brushes of a dynamo

if the sparking is to be reduced to a minimum? Why, also, must a backward or negative lead be given to the brushes of a motor? [Ord. 1892.]

17. Why is a starting resistance used with a direct-current motor? Describe, with a sketch, the details of the starting resistance employed with a shunt motor. [Ord. 1897.]

18. Describe in detail, with sketches, a starting resistance for use with a shunt motor. [Ord. 1900.]

19. Explain fully why a shunt motor used on constant pressure mains runs at a practically constant speed independent of the load. [Ord. 1897.]

20. A shunt motor running on constant pressure mains is found not to run quite so fast as is desired. Describe the easiest way of increasing its speed, and explain why the plan you suggest would accomplish the desired result. [Ord. 1901.]

21. It is desired to run a shunt motor at varying speeds when supplied with current at constant pressure. What are the advantages, disadvantages, and limitations, if any, of adopting one or other of the following arrangements:—

(*a*) Varying the speed by means of a rheostat in series with the armature?

(*b*) By means of a rheostat in the shunt circuit? [Ord. 1901.]

22. A shunt motor constructed for use on a 100-volt circuit has to be re-wound for 200 volts. State exactly what changes must be made in the cross-section of the wires on the field magnet and armature respectively, in order that the motor may run at the same speed and work with the same efficiency as before. The difference in the space occupied by the insulating material in the two cases may be neglected. [Ord. 1899.]

23. A 4-pole motor armature, 24 inches diameter, series-wound with 202 external conductors, takes 300 amperes at 210 volts. Flux of lines from one pole 9,000,000 C.G.S. measure (or 1,500 lines English measure).[1] Assume field magnets to be separately excited, and

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[1] What is here referred to as "English measure" is not, by the way, generally accepted, though useful. They are Kapp lines. Thus one Kapp line = 6,000 C.G.S. lines, and consequently 9,000,000 C.G.S. lines = 1,500 Kapp lines. (§ 20.)

armature to work with 95 per cent. efficiency. Find (*a*) speed, (*b*) horse-power, (*c*) tangential pull of armature conductors. [Ord. 1893.]

24. A motor, ring-wound, two-pole, is required to give out 10 h.p. when used on mains at 150 volts. Assuming that its commercial efficiency will be 86 per cent., what current must it take? Also, assuming that its armature is not to run above 600 revs. per minute, and that the iron in its core has a nett cross-section of 20 square inches, how many turns must be wound on the ring? Use your judgment as to the degree of saturation of the armature core. [Ord. 1892.]

25. A compound-wound dynamo when running at 1,200 revolutions maintains a potential difference of 100 volts when the current produced is 50 amperes. If you desired to run it as a motor, would you alter the machine in any way? What speed would it run at if joined up to 100 volts constant pressure mains, and what horse-power would it give out? [Ord. 1898.]

26. How would you wind a medium-sized motor (say 10 h. p.) to run at a constant speed with varying load? And how would you start such a motor? [Ord. 1895.]

27. It is found that a motor (shunt-wound, separately excited, or series-wound) that is supplied from mains at constant pressure runs faster if its field magnet is weakened. Explain (1) the reason for this fact; (2) what arrangements you would make to weaken the field magnet in the case of each of the three sorts of motors mentioned. [Ord. 1896.]

28. Give a diagram representing the connections and switching arrangements required to enable a series-wound motor to be run in either direction at will. State whether you would use a series or shunt-wound motor, (*a*) if it were required that the speed should be constant with a variable load, (*b*) if it were required that the torque exerted by the motor should be practically constant with a variable speed, or greater at low speeds. Give the reason for your preference in each case. [Ord. 1900.]

29. You are required to arrange an electro-motor to drive a lathe, and another motor to drive a fan, in a building supplied with current from constant pressure mains. What kind of motor would you select in each case, and for what reasons? [Ord. 1901.]

30. Describe generally the advantages and disadvantages that

would be produced by replacing the ordinary shaft and belt driving of machines in a factory with electric driving of each individual machine, or of each set of machines. [Ord. 1901.]

31. State precisely what you would conclude was wrong with a continuous current shunt motor in each of the following cases :—

1. On switching on with a light fuse, the fuse immediately blows. On putting in a stronger fuse it starts off at an excessive and increasing speed, the direction of rotation being perhaps reversed.
2. The motor appears to run fairly well excepting that there is a bright spark at each set of brushes which, it may be observed, occurs once every revolution of the armature.
3. The armature takes an excessive current, and, on stopping, a coil is found to be heated or perhaps burnt out. [Ord. 1902.]

32. State how much is (approximately) the rated power of motors used in electrical tramcars. Also state on what it is, in an electric motor, that the torque or turning moment depends. [Ord. 1896.]

33. Describe a simple form of brake suitable for testing the power given out by a motor up to, say, 10 h.p., and give sketches showing the principal dimensions. [Ord. 1898.]

34. An electric tram-car of 10 tons rolling weight is required to run up an incline of 1 in 60 at a uniform speed of 7 miles per hour. The resistance to traction on a level line is 30 lbs. per ton, and the total or combined efficiency of the propelling mechanism (ratio of mechanical power utilized to electric power supplied) is 57 per cent. What is the electric horse-power which must be supplied? And what is the current required if the supply is at a constant pressure of 300 volts? [Ord. 1892.]

35. An electric tram-car, total weight 10 tons, runs upwards on an incline of 1 in 100. The motors and gear are such that for every ampere passing through the armature there is exerted a tractive effort of 10 lbs. The resistance to traction on the level is 30 lbs. per ton. How many amperes are required to propel this car up the incline? Give the horse-power corresponding to a speed of 4 miles per hour. [Ord. 1893.]

35A. Work out the examples given on pp. 366 and 367 by means of the simplified formula :—H.P. = $\cdot 0114\, n\, T$ (§ 110).

36. Give a sketch of a tramway motor and the arrangements for altering its speed and the direction of rotation. [Ord. 1897.]

37. Give sketches of a "controller" on an electric tramcar, and explain exactly how it acts. [Ord. 1898.]

38. What is meant by "series-parallel-control" in electric tram-car work? Explain how its adoption affects the problem of starting the car from rest with the minimum waste of energy; give sketches. [Ord. 1900.]

39. Describe, with sketches, a series-parallel controller for an electric tramway, stating the connections made by it at each step. What is meant by a magnetic "blow-out," and how does it operate? [Ord. 1901.]

40. Describe briefly the trolley-wire, conduit, and surface contact systems of electric traction, and point out their relative advantages and disadvantages. [Ord. 1899.]

41. What torque in inch lbs. must be exerted by each of the two motors on a tram-car weighing 10 tons, so that on a level track they may produce an acceleration of 1·2 ft. per sec. per sec.? Tractive force 30 lbs. per ton; gearing ratio 4·8, wheels 33 ins. diameter; efficiency of gearing 85 per cent. [Ord. 1902.]

42. Describe one kind of alternate current motor. [Ord. 1895.]

43. What are the advantages and disadvantages of polyphase and single-phase alternate current motors? [Ord. 1901.]

44. A three-phase motor is supplied with currents having a frequency of 50. What speed will it run at if the inductor has 15 poles and the slip is 3 per cent.? [Ord. 1901.] *This question is vaguely worded. What is probably meant is that there are* 15 *pairs of poles,* i. e. 30 *in all; or* 10 *poles per phase.*

45. A motor driven generator is being used to charge a storage battery, the motor being protected by an overload cut-out. Describe exactly what will happen if the exciting current of the motor is steadily diminished. [Ord. 1903.]

46. An electrically driven railway train, weighing 100 tons, travels 10 miles along a line which rises 600 ft. in the distance, the tractive force on the level being 12 lbs. per ton. Find the number of kilowatt hours required to do the work, efficiency of motor and gearing being taken at 82 per cent. [Ord. 1903.]

CHAPTER XV.

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.); and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

*148. CHEMICAL EFFECT OF THE CURRENT. ELECTRO-

LYSIS.—When electricity is passed through solutions of certain chemical compounds, the latter are split up into their constituents. This action of electricity is termed *electrolysis,* and the solution which is split up is called the *electrolyte.* The current is led into and out from the solution by means of conducting plates of lead, carbon, platinum, or other metal; according to the nature of the solution to be electrolyzed, and the required disposition of the liberated constituents of the electrolyte. The plate by which the current enters the solution is named the *anode,* and the plate by which it leaves is named the *kathode.* These plates are also termed *electrodes;* the anode being the + electrode, and the kathode the − electrode. The constituents into which the electrolyte is decomposed or split up are called *ions;* and they are liberated from the solution at the surfaces of the anode and kathode. That which appears at the anode is named the *anion;* while that which is liberated at the kathode is termed the *kation.*

*149. ELECTROLYSIS OF WATER.—If electricity be passed through water, the latter will be split up into its constituent gases—hydrogen and oxygen. As water itself is a comparatively bad conductor, it is necessary to acidulate it slightly with a few drops of, say, sulphuric acid, which has the effect of greatly increasing its conductance. A simple form of apparatus for use in the electrolysis of water is shown in Fig. 257. Two platinum wires, mounted on insulating supports affixed to the base of the glass vessel, form the electrodes; and these are connected by means of copper wires with the terminals outside. Platinum is used in order that the electrodes should not be attacked by the liberated gases, or the acidulated water. Over

these wires, and resting on their supports, are placed two glass tubes, with one end of each corked up.

The glass vessel is nearly filled with acidulated water, and the inverted tubes completely so. Then when current is passed through from three or four suitable cells, the gases which are given off in the form of bubbles at the electrodes, rise in the tubes, and displace the water therein. Oxygen, being the anion, will be liberated at the surface of the anode; the kation (hydrogen) appearing at the kathode. The gases may be tested as follows :—the hydrogen will burn with a pale blue flame, but will not support combustion; so that if a lighted match be plunged right into it, the flame will be extinguished. The oxygen will not burn, but being a very good supporter of combustion, will make a lighted match burn more brightly; and will even cause a glowing match to burst into flame. Moreover, it will be noticed that about twice as much hydrogen as oxygen will be liberated, thus demonstrating the proportion in which these gases are combined in water, viz. H_2O, *i. e.* two volumes of hydrogen to one of oxygen.

FIG. 257.—Electrolytic Cell (Gen. Elec. Co.).

*150. ELECTROLYSIS OF COMMON SALT.—Fig. 258 shows a V-tube clamped in a stand, and having platinum wires (attached to the ends of copper ones) suspended in the

top of each leg. The tube is filled with a solution of common salt, acidulated with a drop of hydrochloric acid to improve its conductance; the electrolyte being reddened in colour by the addition of a little litmus. Litmus, by the way, is a vegetable colouring-matter which is red in the presence of acid, and blue under the action of an alkali, such as the caustic soda mentioned below.

When current is passed through, from say, a battery *B* of bichromate cells, the chlorine from the solution will be liberated at the anode; and its presence will be denoted by its bleaching or decolourizing action, the liquid around the anode losing its red colour. At the kathode, caustic soda will be formed; and the litmus colouring of the solution around it will be turned blue thereby.

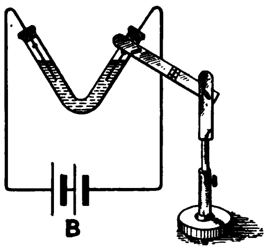

FIG. 258.—Electrolysis of Common Salt.

Common salt, or chloride of sodium, is a combination of sodium (Na = Natrium) and chlorine (Cl.), and is indicated thus, NaCl. The chlorine is liberated at the anode, and the sodium unites with the water to form NaOH, or caustic soda, at the kathode.

*151. ELECTROLYSIS OF COPPER SULPHATE.—Take a vessel containing a solution of copper sulphate crystals in water. Use clean lead plates as electrodes, and send a current through the electrolyte from a battery of three or four cells. After the action has been going on for about five minutes, it will be found on examination that the kathode has received a coating of freshly-deposited copper, while

the anode has somewhat darkened in colour, owing to slight oxidation. If the current be now reversed, the oxidized plate will receive a deposit of copper, and the plate which was previously coppered will darken in colour, the copper being slightly oxidized owing to the liberated *sulphion* (SO_4) uniting with the hydrogen of the water to form sulphuric acid (H_2SO_4), and setting free oxygen. This reaction may be graphically illustrated as follows:—

Before Electrolysis.

Kathode|| $CuSO_4$ (Copper Sulphate) ||Anode

After Electrolysis.

Kathode|| Cu (Copper) SO_4 (Sulphion) ||Anode

$\longleftarrow$

Direction of current.

It is useful to remember that when solutions of metallic compounds are electrolyzed, *the metal always travels through the solution in the direction of the current, and is thus deposited on the kathode.*

152. THEORY OF ELECTROLYSIS.—The theory about to be expounded is partly due to Grotthüss, and partly to Clausius. All the chemical elements have different "electrical values" so to say: that is, some are more "electro-positive" or "electro-negative" than others. In other words, the atoms of any one element, when in a temporary free state, may be supposed to be either + ly. or – ly. charged. Thus the elements may be arranged in an order, beginning with those which are most "electro-positive," and ending with those which are most "electro-

negative." In any solution, the molecules of the different constituents may be considered as wandering aimlessly about in a crowd; and the molecules of like matter may be supposed to be constantly interchanging their atoms. The atoms, being set free, roam about until they meet with other free or uncombined atoms, when they form new molecules. This is what may be presumed to take place in an electrolyte. When the electrolyte has no flow of electricity through it, the setting free and recombination of the atoms take place without any definite direction of movement on their part. But when a current is sent through the electrolyte, or in other words, when a P.D. is set up between the electrodes; the most highly "electro-positive" constituent or ion of the electrolyte travels in one direction, and the least "electro-positive" (or it may be "electro-negative") constituent travels in the other direction. Thus it is that we get the liberation of certain ions at the electrodes, and at the electrodes only.

The electro-positive ions will appear at the surface of the kathode or − plate; while the electro-negative ions will appear at the anode or + plate. As the anode and kathode may be presumed to be slightly positively and negatively charged, respectively; the action of electrolysis may, to some extent, be further explained by supposing that the electro-negative ions (for instance) are repelled by the kathode and attracted by the anode. Hydrogen, sodium, and copper are electro-positive, while oxygen and chlorine are electro-negative. The reader should refer to §§ 149—151, and see that the results there obtained agree with what has just been said.

*153. LAWS OF ELECTROLYSIS.

(i.) FARADAY'S LAW.—*The amount of chemical action effected by the passage of a current through an electrolyte is directly proportional to the strength of the current, and to the time of its flow in seconds.*

The amount of chemical action brought about is thus a measure of the total quantity of electricity which has passed through the electrolyte; because current (in amperes) × time (in seconds) = coulombs (Chap. *II.*). In other words, *the amount of chemical action effected is directly proportional to the number of coulombs which have passed through the electrolyte.*

(ii.) SECOND LAW.—*The quantity of an ion (in grammes) liberated in a given time is equal to the "electro-chemical equivalent" of the ion multiplied by the strength of the current, and by the number of seconds that it flows.*

In other words, *the number of grammes liberated is equal to the "electro-chemical equivalent" multiplied by the number of coulombs that are passed through the electrolyte.*

The *electro-chemical equivalent* of any given ion is equal to its atomic weight divided by its valency and multiplied by ·000010384; the latter figure being the weight of hydrogen (in grammes) set free by one coulomb. The *atomic weight* of an ion is the weight of one of its atoms as compared with that of an atom of hydrogen, which is taken as unity. The *valency* of an ion (expressed by one of the numbers 1, 2, 3, or 4) depends on the number of atoms of hydrogen, or other element with single valency, that combine with one atom of the ion in question. Thus the valency of chlorine is 1, for one atom of chlorine unites with one of hydrogen to form hydrochloric acid (HCl).

Oxygen has a valency of 2, for it requires two atoms of hydrogen to enter into combination with one atom of oxygen to form water (H_2O). Tables of atomic weights, valencies, and electro-chemical equivalents will be found in any treatise on electro-chemistry.

The quantity of electricity passed through an electrolytic cell is usually computed in *ampere-hours;* one ampere-hour being equivalent to $1 \times 60 \times 60 = 3600$ coulombs or 3·6 kilocoulombs (Chap. *II.*).

Practically speaking, electrolysis can only take place with direct currents, for as the chemical action depends upon the direction of the current, if an alternating current were passed through an electrolyte, the chemical action would in most cases be reversed with each reversal of the current, so that the resultant effect would be nil.

154. Electrolysis by means of the Arc.—While dealing with electrolysis it may be mentioned, by the way, that there are innumerable electro-chemical processes which may be effected by its aid; the branch of electrical engineering dealing specially with these being termed *electro-chemistry.*

Electrolysis may not only be conducted by passing currents through solutions, but also by subjecting substances to the heat of the electric arc. We may cite as examples of the latter method, the production of aluminium, calcium carbide, and carborundum.

Aluminium occurs in nature in various rocks, and also in clay, marl, slate, and several crystalline minerals. One of the latter, named bauxite, is a compound of sodium, aluminium, and iron. This is treated chemically to form hydrate of alumina, and the latter is then mixed with certain minerals and subjected to the heat of the arc in an

electric furnace. The latter takes the shape of a carbon vessel forming both the "bath" and the kathode, while a number of carbon rods with their ends in the mixture act as the anode. A very large current at 100 volts or so is then applied, and the various arcs formed in the furnace heat up the hydrate, and set aluminium free in a molten condition.

Calcium carbide is also prepared in an electric furnace, from a mixture of lime and coke. A mixture of coke, sand, sawdust, and salt, similarly treated, results in the production of carborundum, an extremely hard crystalline substance which is used as a substitute for emery.

*155. SECONDARY CELL.—A *secondary cell* or *accumulator* differs from a primary cell in that its elements or plates have first to be put into the necessary chemical condition by means of electrolysis. In other words, it has first of all to be "charged"; that is to say, a current of electricity must be passed through it for some time before it is able of itself to exert electromotive force, and so set up a current. Thus it will be seen that it is not electrical, but chemical energy which is stored up in charging a secondary cell or battery. On this account the term *secondary battery* is more correct than either of the terms *storage battery* or *accumulator;* for the latter much-used names tend to convey to the mind of the novice the erroneous idea that it is electricity which is stored up.

A simple form of secondary cell may be made from two clean lead plates dipping into dilute sulphuric acid (say 1 part of acid to 10 parts of water). If, while in this condition, the lead plates be connected by wires with a galvanoscope or current-detector, no current will be observed; for

the simple reason that a cell having similar electrodes cannot exert much, if any, electromotive force. If, however, a current from three or four primary cells (bichromate, for example) be passed through this arrangement for five or ten minutes, the condition of the lead plates will be altered. The anion (O) will attack the anode or + plate, and peroxidize it, as will be seen from the reddish-brown film of lead peroxide (PbO_2)[1] which appears on its surface; while the kathode will be but very little changed. In this condition the cell is able to exert E.M.F., as will be readily seen if it be connected once again with the detector. The action may be simply expressed as follows:—

(*Uncharged*) (Anode) $Pb|H_2O+H_2SO_4|Pb$ (Kathode)
(*Charged*) $PbO_2|H_2O+H_2SO_4|Pb$.

When the cell is charged, that is, when the surface of the anode has been converted into PbO_2 (lead peroxide)—the kathode being still plain lead, for the liberated hydrogen does not combine with it—we may use it as a source of E.M.F., or roughly speaking, we may take current from it. In so doing the cell gradually becomes discharged.

In the process of discharging, the acid in the electrolyte acts on both plates, and forms sulphate of lead ($PbSO_4$) thereon. Thus:—

(*Discharged*) (Anode) $PbSO_4|H_2O+H_2O|PbSO_4$ (Kathode).

As long as any peroxide of lead is left on the surface of the anode, the cell will continue to give current; but the more it is discharged, the greater will be the amount of PbO_2 changed into $PbSO_4$. If the cell were fully discharged, both plates would be completely coated with the sulphate,

[1] Pb = Plumbum = Lead.

and being then in exactly the same chemical condition, no E.M.F. would be produced. As is mentioned later on, however, a cell must never be completely discharged.

A second charge will bring back the plates once more to the state:—

(*Recharged*) (Anode) $PbO_2|H_2O + H_2SO_4|Pb$ (Kathode).

This is only a rough way of expressing the chemical changes which take place in the cell, and which, by the way, are not even yet very thoroughly understood. It is important to observe that the sulphuric acid solution is strongest when the cell is fully charged; and that it gradually weakens, owing to the sulphating of the plates, as the cell is discharged, recovering its strength once more when the cell is recharged. The specific gravity of the solution consequently varies with the condition of the cell, which fact enables the latter to be ascertained by means of a hydrometer, as explained in § 184.

Starting with plain lead plates, we find that the kathode becomes sulphated during discharge, but returns to its condition of plain lead on recharge. The surface of the kathode, however, is left in a slightly porous condition. This porous part of the lead plate, which is increased by repeated chargings and dischargings, is known as *spongy lead.* If the cell be repeatedly charged, first in one direction and then in the other, the surfaces of both plates will be rendered spongy or porous, and the action of the cell will be much improved.[1]

[1] Some form of bichromate battery is best for electrolytic experiments, and the charging of small accumulators; Leclanché or dry cells being quite unsuitable for such work, as they polarize so rapidly (see the Author's *First Book of Electricity and Magnetism*). If a

*156. Capacity of Secondary Cells.—The amount of energy which can be stored up in two simple lead plates, depends upon the quantity of lead peroxide formed on the anode or + plate; and this again depends a great deal upon the amount of surface exposed to the electrolyte. After a cell, such as has just been described, has been repeatedly charged and discharged in opposite directions,

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direct-current lighting supply be available, current for such experiments may conveniently be drawn from the mains. For this purpose, the arrangement of switches, lamp-holders, etc., shown diagrammatically in Fig. 259 will be found useful. *S* is a row of tumbler switches mounted on the top of the lid of a box, and *L* a row of lamp-holders preferably fixed on the underside of the lid, so that the lamps may be shut up in the box, and the glare from them avoided. The sets of switches and holders are connected in parallel across the terminals *T*, *T*+, each set consisting of a switch in series with a lampholder. A third terminal *T*−, by the side of *T*+, is connected through the main switch *MS* and fuse *F* with a fourth terminal *T′*. *T* and *T′* are joined up by wires *W* with a pair of terminals on the distribution board in the building, the fuse *F* being made somewhat lighter than the double pole fuses on the board. The terminals *T* and *T′* are purposely put far apart, as the full voltage of the circuit is between them, and a short circuit would cause rather bad sparking and the rupture of the distribution-board fuses. The electrolytic or secondary cell, or other apparatus for which current is required, is connected to the terminals *T*+ and *T*−. Lamps being inserted in the holders at *L*, the current flowing through the apparatus can be regulated by turning on one or more of the switches *S*. By using lamps of 8, 16, 25 or higher candle-power, the additions of current when the switches *S* are put "on" can be regulated as desired. With a given apparatus in circuit, the P.D. between *T*+ and *T*− will increase as the number of lamps switched on is increased. The available pressure between *T*+ and *T*− can also be increased by using lamps of slightly lower voltage than that of the supply circuit. The main switch *MS* enables the current to be turned on or off directly.

the surfaces of both plates become more and more porous. The electrolyte soaks into this porous surface, and thus a greater amount of lead peroxide is formed on the anode during the charging. With each successive charging and discharging, the active surface of the anode is further increased; and more spongy lead is formed upon the kathode plate. The latter in this condition more readily forms $PbSO_4$, as is necessary in the action of the cell.

This formation of spongy lead on both plates, which is called *forming*, may, as mentioned in the preceding paragraph, be effected by alternately charging the cell, discharging it, and charging it again in the reverse direction. "Forming" has the effect of increasing the *storage capacity* of the cell.

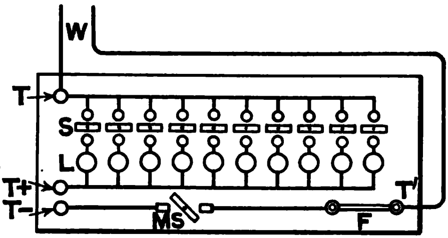

FIG. 259.—Current Regulator.

It should be noted that the charging current in a secondary cell is in the opposite direction to the current of discharge.

*157. PLANTÉ'S SECONDARY CELL.—The original type of cell, invented by M. Gaston Planté, is shown in Fig. 260. It consisted of two sheets of lead rolled up together, with some strips of insulating material interposed to prevent metallic contact between the plates. This roll of lead was then immersed in an electrolyte consisting of a solution of 1 part of pure sulphuric acid in 10 parts of water. The "forming process" was managed as follows. The cell was

charged until gas was freely given off from the plates, this denoting that the available surface of the anode was fully peroxidized. The cell was then discharged, and charged the opposite way to the previous charge; this alternate charging and discharging having to be repeated several times before the cell acquired any degree of capacity.

*158. "FORMING" OF PLATES.—In forming the plates as above described, it was found advisable to allow a period of some days to elapse between each reversal of the current. During this period of rest, the thin film of PbO_2 on the + plate decomposed the sulphuric acid, and formed lead sulphate ($PbSO_4$), this practically discharging the cell. When the current was reversed, the $PbSo_4$ was reduced by the nascent (newly liberated) hydrogen, and the amount of finely-divided or spongy lead thus greatly increased.

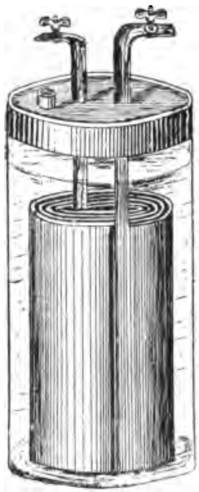

FIG. 260.—Planté's Secondary Cell.

To accelerate still further their formation, Planté treated the plates with dilute nitric acid, which thoroughly cleaned and slightly roughened their surfaces: and during charging he heated the cell, this having the effect of opening the pores of the metal, and allowing the electrolyte to penetrate more deeply into the plates. Cells of the Planté type have since been much improved by different inventors and manufacturers; the main objects being to hasten the formation, and increase the storage capacity and durability of the plates,

and also to reduce their weight. The cells described in § 166 are of this type.

*159. PASTED AND GRID PLATES.—Before the improvements in the Planté type of secondary cell, just referred to, were effected; a process was devised by Faure in which the plates were plastered over with a paste made of *red lead* (red oxide of lead, Pb_3O_4) and sulphuric acid, this mixture forming lead sulphate. In the charging of the cell, the paste on the + plate was reduced to PbO_2, and that on the − plate to spongy lead; so it will be seen that by this plan the formation of the plates was greatly accelerated.

The main drawback of the original Faure cell was the difficulty of getting the paste to adhere to the lead plates. This was overcome at last by casting them in the form of *grids*, i.e. with perforations wherein the paste could be packed. In modern cells the negative plates are nearly always in the form of grids; but the positives in most cases are solid in the centre, with ridges on each side. The paste for the negative plates is now usually formed of *litharge* (lead monoxide, PbO) and sulphuric acid; that for the positive plates being made of red lead and acid as above described.

*160. SIZE OF CELLS.—All secondary cells, except the very smallest, have a number of positive and negative plates arranged alternately and close together, but without touching; all the + plates being connected to one or more cross-bars, and the − plates to similar bars separated from the positive ones. Fig. 261 gives some idea of this arrangement, and represents, in plan, a 13-plate cell with 6 positives and 7 negatives, the former being shown black. *B*, *B* are the bars to which the plates are attached, and +

and − the terminal lugs of the cell, by means of which it may be connected to others. There is always an odd number of plates, there being one more negative than positive, so that none of the positive surface is wasted. In the figure for example, if the end negative *N* were done away with, and the number of plates thus made even, the side *S* of the end positive would be rendered inactive.

The number of plates varies from 3 to 33 or more, according to the desired capacity of the cell (§ 162); and the latter depends on the size of the plates, as well as on their number.

*161. E.M.F. OF CELLS.—In the charging of a secondary cell, the P.D. that must be applied must exceed a certain value, which is a measure of the tendency of the ions (§ 148), to recombine. In other words, directly one begins to charge a cell, the liberated ions set up what is virtually an E.M.F. in the contrary direction to the charging E.M.F.; this *back E.M.F.* gradually rising to a maximum of about 2·2 volts per cell at full charge. In order to charge a single cell, a P.D. of at least 2·5 volts should be available; and if two or more cells are to be charged, this charging P.D. must be multiplied by the number of cells (in series) comprised in the secondary battery. Thus, if the latter consists of 53 cells, the available charging P.D. must be equal to about $53 \times 2{\cdot}5 = 133$ volts.

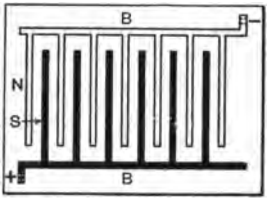

FIG. 261.—Diagram of Secondary Cell.

On discharging, the E.M.F. of a cell drops very rapidly from about 2·2 to 2 volts; and after remaining steady for

some time at 2 volts, would gradually drop to zero if it were fully discharged. But it is one of the first rules of secondary battery management that the E.M.F. must never be allowed to fall below 1·85 volts per cell, otherwise the deterioration of the battery will be very rapid.

162. CAPACITY AND EFFICIENCY.—The charging or discharging E.M.F. of a cell is practically independent of its size, but on the latter depend its *charging* and *discharging currents*. These are determined chiefly by the number and size of the positive plates, or, in other words, by the total superficial area of peroxidized plate, reckoning both sides. Varying with the construction of the cell, the charging current may be from 4 to 8 amperes per square foot of plate. The normal discharging current is practically equal to the respective charging current.

On the size of a cell depends also its *ampere-hour capacity*, i. e. the number of ampere-hours required to charge it, or the number of ampere-hours it will give out on discharge. Capacity may also be reckoned in watt-hours or kilowatt-hours, this method being generally applied to a battery of cells; as to mention the capacity of the latter in ampere-hours would be inconclusive unless we knew the number of cells, and consequently the voltage of the battery. The ampere-hour capacity merely tells us the quantity of electricity which has to be put in in charging, or which may be got out on discharge; whereas the watt-hour capacity deals with the quantity of electrical energy put in or given out, or, in other words, the amount of work expended on or done by the battery.

The ampere-hour capacity multiplied by the average

voltage of the cell or battery will give the watt-hour capacity.

The discharging capacity is naturally less than the charging capacity, as it would be impossible to get the same number of kilocoulombs out of a cell as were passed through it in charging; some of the energy having necessarily to be expended in the double process of conversion from electrical to chemical energy and back again to electrical energy.

A cell with a given capacity may be charged or discharged at different rates, but there are limits to be observed. Thus a cell with a charging capacity of 400 ampere-hours might be charged in 10 hours with 40 amperes, or in 8 hours with 50 amperes: but the attempt to charge it in, say, 4 hours with a current of 100 amperes would only result in the ruin of the cell. In discharging a cell there is also a limit to the current that may be drawn from it, *i.e.* to its rate of discharge; but it does not matter, of course, how *slowly* the discharge is conducted. *The discharge capacity of a cell depends upon the rate of discharge.* With every given type and size of cell there is a maximum discharge current which must never be exceeded. A cell discharged at its highest rate will only have half (or less than half) the capacity it would possess if discharged at a low rate. In other words, the discharging capacity of a cell is not a hard-and-fast quantity; for the smaller the current drawn from it, the greater will be the number of ampere-hours it will give out before its E.M.F. falls to the prescribed minimum.

All the cells in a series battery must be of equal capacity, and the ampere-hour capacity of a battery of a single

string of cells in series is exactly the same as that one cell. The watt-hour capacity, however, depends on the number of cells. If the battery comprises two parallel rows of equal-sized cells, its ampere-hour capacity will be double that of one cell. The E.M.F. of a battery is proportional to the number of cells in series; but the P.D. depends on their size (*i. e.* their resistance) and on the discharging current.

The *ampere-hour efficiency* of a cell is the ratio of the discharge to the charge, both being reckoned in ampere-hours. The *watt-hour efficiency* of a cell or battery may be obtained by dividing the amount of energy (in watt-hours) given out during discharge, by the amount expended in charging it (sometimes incorrectly called the *charging power*). The watt-hour efficiency of a cell or battery can never exceed about 80 per cent.

The efficiency of a cell or battery is not a fixed quantity, but varies with the charge and discharge rates; it also depends on the period which elapses between charge and discharge. If the charge of a cell is not hurried, and no great time is allowed to elapse between charge and discharge, and it is discharged at a low rate, the cell will give its best efficiency (p. 485).

163. WEIGHT AND CAPACITY.—The *weight efficiency* of cells is indicated by the ratio between the discharging capacity and weight; and depends chiefly on whether the cells are intended for stationary or for vehicular, launch or other portative work; a high weight-efficiency being generally only secured at the expense of durability. Broadly speaking, for stationary work, the weight of a complete cell (in pounds) will vary from one-third to one-half the number expressing its ampere-hour capacity at the normal

rate of discharge. Thus, if a cell has a normal capacity of 300 ampere-hours, its weight will probably be between 100 and 150 pounds.

For rough calculations, it may be assumed that for every horse-power-hour (746 watt-hours) of energy which it will give out, a battery will weigh one hundredweight.

In traction cells, where lightness is essential, the capacity may be 6 or 7 ampere-hours for every pound of weight; so that a cell weighing 7 pounds will give between 40 and 50 ampere-hours discharge.

164 Modern Types of Cell.—Since the pioneer work of Planté and of Faure, quite an army of inventors have exercised their ingenuity in devising secondary cells; but the number of different makes at present on the market is comparatively small, and there is a strong family likeness between them. We shall now proceed to describe and illustrate examples of six accumulators of different manufacture, these being:—

(1) The E.P.S.
(2) The Chloride.
(3) The D.P.
(4) The Tudor.
(5) The Marquand.
(6) The Monobloc.

Most of these makes of cell are divided into various types, according as they are for stationary or portative work. Of the former class there are different kinds, constructed for rapid, medium, and slow discharges. The portative cells are built up in various forms, for vehicle, tram-car and launch driving; ship, train, or tram-car lighting; medical and theatrical purposes, and so forth.

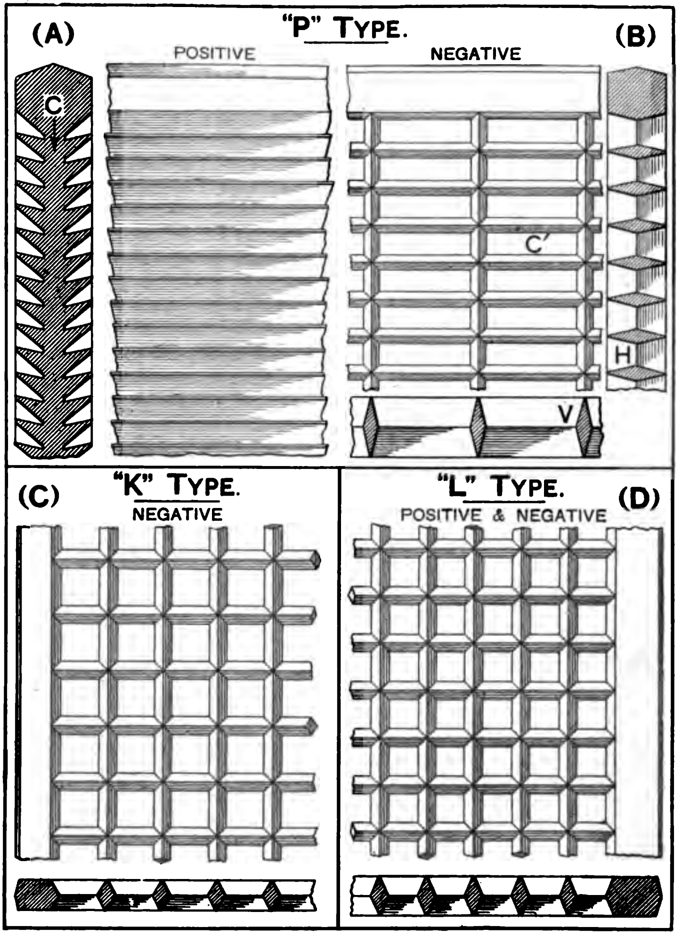

FIG. 262.—Portions of E.P.S. Plates (Scale—Full Size).

Stationary cells are usually contained in glass boxes, and portative cells in lead-lined wooden boxes, or, in the case of very small cells, in ebonite cases. The number of different types and forms is, in fact, so large; that only a few representative ones of each make can be described.

*165. THE E.P.S. CELLS.—There are four chief types of these cells for stationary purposes, viz. the "*P*," the "*WS*," the "*K*," and the "*L*" types; and several for traction, train-lighting, and other portable work. Their name is formed by the initials of the makers, the Electrical Power Storage Company.[1]

The "P"-type has been designed for central stations for electric tramway and power work, where extremely heavy and more sudden demands are made than in lighting work only. These cells may be discharged in one hour if necessary. Full size elevations and sections of portions of the + and − plates, which, by the way, are about 14 inches square, are given in Fig. 262 at *A* and *B*. From these it will be seen that the + plate is solid in the centre, as at *C*; while the − plate is in the form of a grid. The walls of each little cell, *C'*, in the latter, are so shaped that the spongy lead lozenge formed therein is keyed in place. This formation is shown at *V* and *H*, which give sections of the vertical and horizontal bars of the grid. The "honeycombing" in this and in most other grid plates is strengthened by thick vertical and horizontal bars, as indicated at *B*, *B*, *B* in Fig. 263. This figure shows the outline of a "P"-type negative plate; a small portion only of the "honeycombing," which corresponds with that at *B* in Fig. 262, being drawn in.

The "P"-type cells, which are usually mounted in lead-

[1] A new "O K." type has recently been introduced.

lined teak boxes, vary in size from 9 to 57 plates. The largest cell, when discharged in one hour, gives a current of 1400 amperes, this being equivalent to a capacity of 1400 ampere-hours. If discharged at a low rate, however, say 420 amperes for seven hours, the capacity is more than doubled, being then 2940 ampere-hours.

Fig. 264 illustrates a 23-plate "WS"-type cell in a glass box, the ordinary sizes having from 5 to 25 plates which measure about $10\frac{1}{4}$ inches square. These cells may be discharged in from 2 to 7 hours; their ampere-hour capacity at the high rate, however, being only half that at the low rate. Thus the cell illustrated has a capacity of 616 ampere-hours with a 7-hour discharge at 88 amperes; but only 330 ampere-hours with a 2-hour discharge at 165 amperes. It would be uneconomical, of course, always to discharge the cells in so short a time as two hours; but they have been specially designed for withstanding such discharges if necessary, and are consequently suitable for central lighting stations.

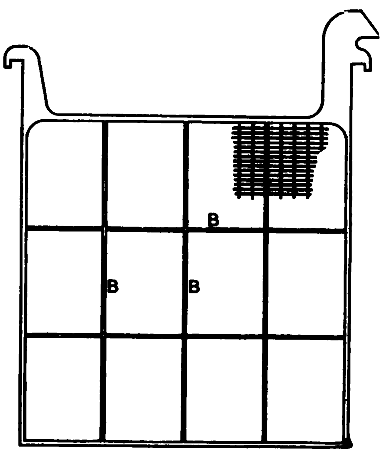

FIG. 263.—"P"-type E.P.S. Plate.

The negative plates stand on (and are connected by feet *F*, *F*, with) two lead bars running along the bottom of the cell, the latter being joined at one end to the broad lead band

forming the negative terminal $T-$. This band is riveted to the end plate P, which, like the plate at the other end, is made with a solid outside backing to the grid. The positive plates are attached to two thick horizontal lead bars L, L, terminating in a cross-piece and terminal $T+$. L, L rest on projections on the upper edges of the negative plates, but are separated therefrom by ebonite saddles E, E. The plates are prevented from touching one another by means of vertical glass tube *separators*, of which there are three rows V. These tubes stand in holes bored in strips of wood at the bottom of the cell, and the two outer rows are kept upright at the top by four horizontal tubes, as at H.

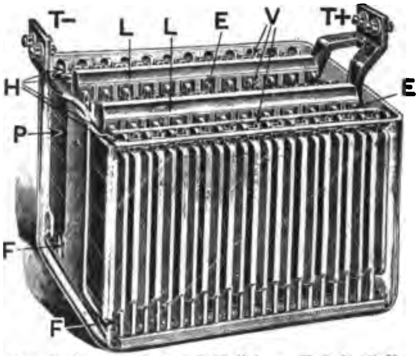

FIG. 264.—23-plate "WS"-type E.P.S. Cell.

The "WS"-type + and – plates are similar to, but on a smaller scale than, those of the "P"-type; the "honeycomb" cells of the – grid being arranged vertically instead of horizontally.

A 33-plate cell of the "K"-type is given in Fig. 265. This pattern is suitable for medium discharge periods of not less than three and a half hours. At this rate, the 33-plate cell, which is the largest stock size, will give 136 amperes with a capacity of 476 ampere-hours; or 80 amperes for seven hours' discharge, *i. e.* 560 ampere-hours. The

negative plates stand on prolongations or feet at each bottom corner, and are connected together by two lead strips resting on wooden strips at the bottom of the cell. These lead strips are joined by a cross-bar to the terminal lug which passes up from the bottom of the cell, and which forms the negative terminal $T-$. Thus, so far the arrangement of the negative plates resembles that in the "WS"-type. In addition, however, they are united by bands at their upper corners. The + plates are connected together and supported at the top by two thick bars; and these bars rest on insulating ebonite saddle-pieces placed on the top edges of the negative plates. The two bars are joined together by a piece of lead bent at an angle, and forming the + terminal $T+$ of the cell. The separators used take the form of ebonite forks, of which there are three rows F. A separate view of one of these forks is given at F'. The + plates of the "K"-type are a replica of those of the "P"- and "WS"- types, only on a still smaller scale. The − grid has square apertures, as shown at C in Fig. 262.

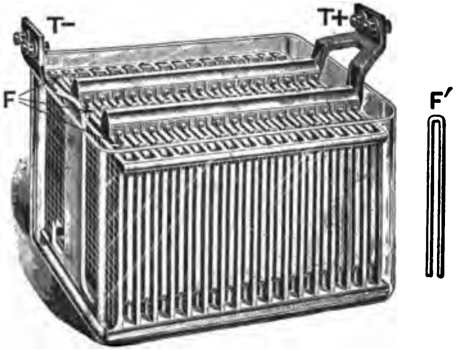

FIG. 265.—33-plate "K"-type E.P.S. Cell.

The "L"-type cell (Fig. 266), which was one of the earliest forms introduced by the E.P.S. Co., is specially

adapted for low and steady discharges, and is thus in much favour for small private lighting installations; the "WS"- or "K"-type being preferable for larger ones, or where much motive power is employed.

As will be seen in Fig. 266, the negatives are held together by five lead bands. Two of these bands form feet for the "section," and rest on blocks of wood placed at the bottom of the cell. Two other of the bands join the – plates half-way up, front and back; and form supports for the positive plates, which have suitable projections on them, ebonite saddles being interposed. The fifth band is the one through which connection is made to the next cell. The + plates are connected by two bands, both on the top, one at one end and the other near the middle of the plates; these forming convenient handles by which the + "section" may be lifted from the cell for inspection. The plates are kept apart by ebonite forks similar to those used in the "K"-type cells. The figure shows the method of connecting the cells together. Each cell rests in a wooden tray filled with sawdust, and each tray is supported by oil insulators (§ 183), two of which are shown at *I*, *I*.

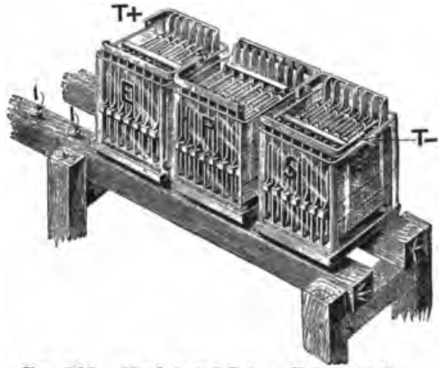

Fig. 266.—15-plate "L"-type E.P.S. Cells.

In the "L"-type cells, both + and − plates are grids of the form shown in Fig. 262 *D*, the only difference being that the positives are slightly thicker than the negatives. The different sizes contain from 7 to 33 plates, measuring about 10 ins. square, the average capacity varying from 130 ampere-hours in the 7-plate cell, to 704 in the 33-plate one.

Space will permit of reference being made only to one

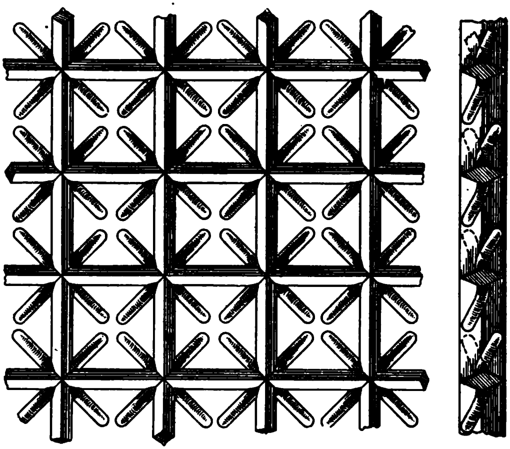

FIG. 267.—Form of Grid in the "FK"-type E.P.S. Cell (Full size).

of the many forms of E.P.S. cell suitable for portative work, this being the Faure-King or "FK" cell. These are specially designed for electric automobile work, and were used in the electric cabs with which we were familiar in London a few years ago. They are fitted in ebonite boxes. Both + and − plates are grids of the peculiar form shown in Fig. 267, each "cell" of the "honeycomb" having a lead "wire" protruding from each corner.

The proportion of active material and of spongy lead to solid lead is thus unusually large, it being necessary, of course, to secure a high weight-efficiency (§ 163). The + plates are wrapped in envelopes formed of perforated sheet ebonite, and ebonite fork-separators are used as well. The envelope effectually prevents short-circuiting, and helps to hold the active material in position. A 9-plate cell is shown in Fig. 268, where the perforated envelopes and the separators will be noticed.

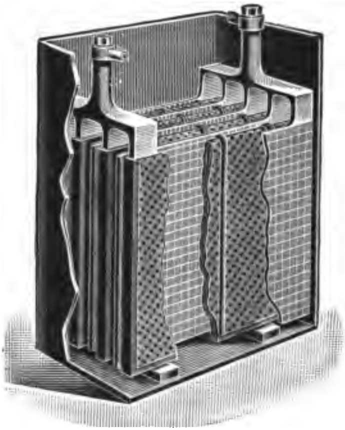

FIG. 268.—9-plate "FK"-type E.P.S. Cell.

Figs. 262 and 267 show the plates and grids of the various cells before the paste is inserted. The latter is made of red lead for the positives, and of litharge for the negatives (§ 159). After a few charges and discharges the plates reach their working condition, the paste on the positives being converted to lead peroxide, and that on the negatives to spongy lead, the former or both of them being often referred to as the *active material.*

*166. THE CHLORIDE CELLS.—These cells are suitable for every kind of work, from central stations down to motor cars; and their construction is such that they are specially adapted to withstand heavy discharges.

The positive plates belong to the Planté type, that is to say, the peroxide of lead or active material on

them is formed by electrolysis, and not by pasting or forcing the lead oxide into ridges or interstices in the plates. The positive grids are cast under hydraulic pressure, with circular countersunk holes in them slightly over three-quarters of an inch in diameter. In these holes are inserted tightly-coiled spirals of gimped lead tape, which, after insertion, are mechanically "riveted" into the apertures by hydraulic pressure, the holes tapering slightly to each surface. Under the subsequent process of formation by electrolysis, the surfaces of these spirals become coated with lead peroxide; and this causes them to expand and key themselves still more tightly into the countersunk holes in the grid; so tightly, in fact, that it requires considerable mechanical force to drive them out. They cannot possibly become detached in ordinary use.

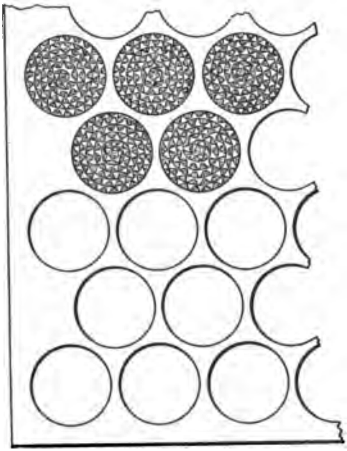

FIG. 269.—Portion of "Chloride" + Plate before Formation (half-size).

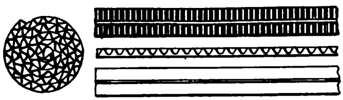

FIG. 270.—Separate Spiral and Lead Tape used in "Chloride" + Plates.

The negative plates consist of lead grids, the "cells" of which are filled with hexagons of spongy lead of a specially pure description. The method of construction is as

follows:—Hexagonally-shaped pastilles are cast from molten chloride of lead, and these are placed in regular order in a mould. The latter is then closed, and molten lead is run in under pneumatic pressure to form the frame, thus

FIG. 271.—Positive Plate of a "Chloride" Cell.

FIG. 272.—15-plate "Chloride" Cell.

completing the plate. Each pastille has two small holes cast in it, which in the first instance are used to hold it in position in the mould, and subsequently serve to promote the circulation of the electrolyte. The plates being thus constructed, the chlorine in the pastilles is removed by placing the plates in an electrolytic cell containing a

solution of zinc chloride, a sheet of zinc being fixed between each pair of plate surfaces. This combination forms virtually a primary cell, and being short-circuited, the nascent hydrogen which is liberated around the plates unites with the chlorine, thus leaving only pure spongy or porous lead. The descriptive name of the cells, "Chloride," is derived from the chemical employed in the manufacture of the negative plates. In Fig. 272, which shows an end

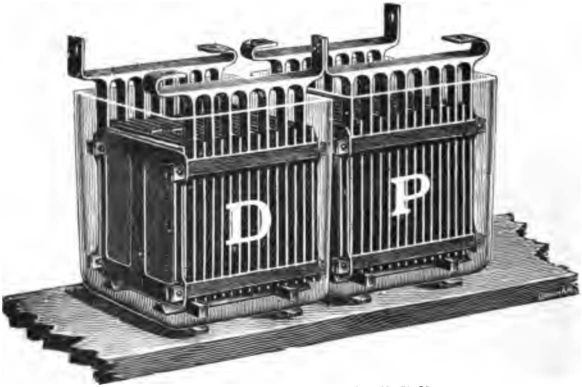

FIG. 273.—15-plate "D.P." Cells.

plate, the hexagonal lozenges of spongy lead, and the two holes through each, can be clearly seen.

Fig. 269 illustrates a piece of + plate with the spirals in position ready for formation; while a separate spiral, with views of the two sides and edge of the lead "tape" of which it is formed, are depicted in Fig. 270. Fig. 271 shows a formed + plate, and it should be noticed that the interstices of the spirals are completely filled up with the lead peroxide.

The containing-cells or boxes may be either of glass or of wood, according to the type and size. Both the positive and negative sections are suspended on stout sheets of glass placed on end, and resting on a paraffined teak bearer at the bottom of the box; and the separators between the plates consist of glass rods. Fig. 272 illustrates a 15-plate cell.

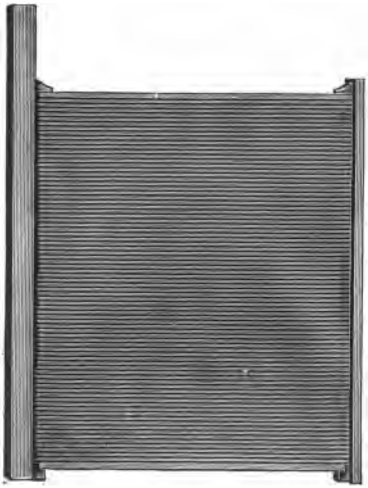

FIG. 274.—"D.P." + Plate.

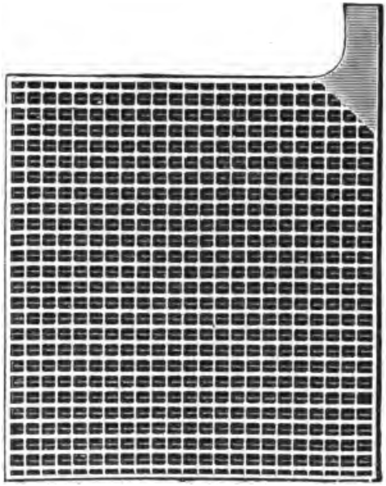

FIG. 275.—"D.P." – Grid.

167. THE "D.P." CELLS.—These cells are intended for general stationary work, and their external appearance may be gathered from Fig. 273, which represents two 15-plate cells (in glass boxes) connected together. The distinguishing letters "D.P." stand for Durability and Power. The plates are spaced half-an-inch apart, with glass tube separators interposed, the + and – sections being bound

together between flat lead end-frames and cross-bars of paraffined teak. The complete section rests on teak bearers at the bottom of the containing-cell.

The old form of positive plate (Fig. 274) was built up of a number of strips stretched horizontally, one above the other, between two vertical side-frame pieces; and was formed without pasting. The negative plate (Fig. 275) is in the form of a grid, an enlarged view of a portion of the plate being given in Fig. 276. This is filled in with the usual litharge and sulphuric acid paste, and the spongy lead formed by electrolysis.

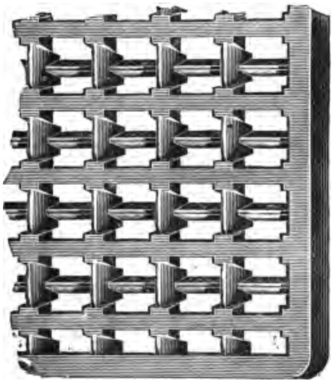

FIG. 276.—Portion of "D.P." Grid (Enlarged).

The "D.P." cells are made up in a number of different sizes, ranging from 3 to 27 plates, and having a maximum capacity of from 60 to 1200 ampere-hours respectively. The plates measure about 10 inches × 9 inches.

In the new type of "D.P." cell, the + plates are of different and stronger construction. Each plate is solid in the centre, with ridges running diagonally across the surfaces, the direction of the ridges on one side being opposite to that of those on the other, so that considerable strength is opposed to buckling. The plates are then formed by the Planté process. Fig. 277 shows one of these new plates, and it should be noted that the lugs on each side are so

shaped as to allow of the plate being supported by the sides of the containing vessel. Yet another new form of + plate has been introduced for heavy charge and discharge work. This somewhat resembles that in Fig. 277, except that the ridges run horizontally.

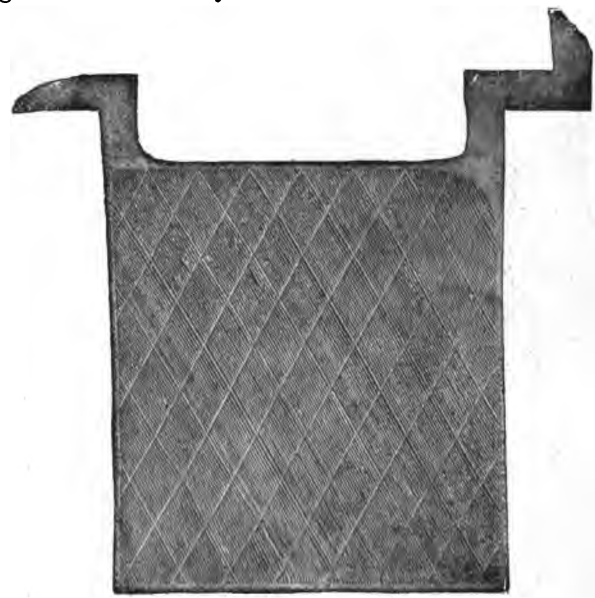

FIG. 277.—New "D.P." + Plate.

168. THE TUDOR CELLS.—Fig. 278 shows a positive plate of this type of cell, the plate being solid in the centre, with a large number of thin vertical ribs on each side, these being strengthened at intervals by horizontal ribs. The whole thickness of the plate is half-an-inch, and the total surface given by the ribbed formation is about ten

times that of a smooth plate of the same size. The plates are formed by the Planté process, plenty of time being given to the formation, so that the film of active material eventually created is regular and adherent. The electrolyte consists of a plain solution of sulphuric acid, without the addition of any corrosive acid or salt such as some makers employ. The negative plates are of the grid type, the form of the grid being shown in Fig. 279.

FIG. 278.—Tudor + Plate.

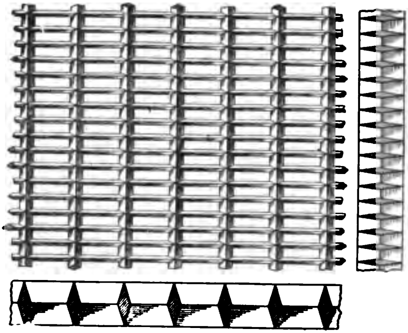

FIG. 279.—Portion of Tudor Grid (½ size).

Fig. 280 illustrates the method of mounting the smaller sizes of cell; the larger being fitted in lead-lined wooden boxes. In the case of glass cells, as in the illustration, the plates are

suspended from the sides by means of the lugs seen in Fig. 278. When wood boxes are used, sheets of glass are stood on end to support the plates. Glass tube separators are employed, these being held upright by fingers cast on the lugs of the negative plates. As will be noticed, plenty of space is left at the bottom of the cells for the accumulation of deposit; this space being 4 inches deep in the case of the smaller cells, and no less than 8 inches in the larger sizes. The cells rest on glass oil insulators, with a disc of sheet lead interposed to prevent breakage. The makers do not consider the sawdust trays used with some cells (as in Fig. 266) to be necessary.

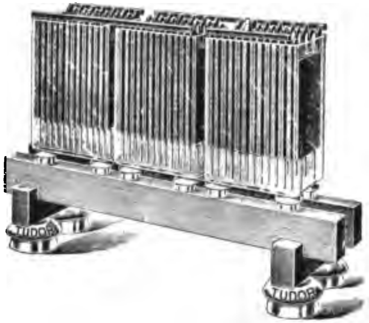

FIG. 280.—Three Tudor Cells.

FIG. 281.—Portion of Marquand Plate magnified.

169. THE MARQUAND CELLS.—The plates of these cells are formed in quite a different way from those hitherto described. A cast plate of large surface is placed in an iron box or frame, and after powdered sulphur has been spread over each side

of the plate, the box is closed up, and heated to a certain temperature in a specially-designed gas-oven. As a result

FIG. 282.—Marquand Cell.

of this, the sulphur combines with the lead to form lead sulphide. The plates are then subjected to a charge in dilute sulphuric acid, and formed into positives or negatives

as desired, the sulphur being reduced, and the lead left ready for peroxidation, or in the spongy state.

As will be seen from Fig. 281, which shows a small portion of a plate magnified to four times the actual size, the surface obtained by the above process is very extended; and the plate is thus suitable for high charge and discharge rates, the E.M.F. being well maintained with the largest currents.

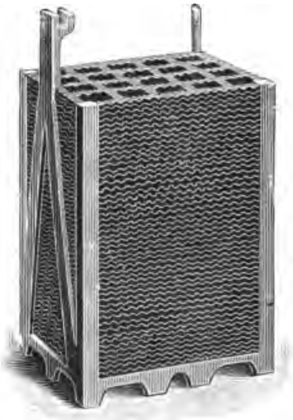

FIG. 283.—Monobloc + Section.

Another important feature is that, owing to the special formation process, the active material is in very intimate contact with the lead backing of the plate, with the result that disintegration and deposit are reduced to a minimum.

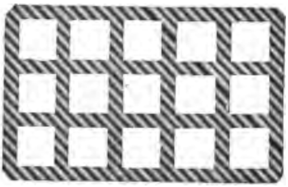

FIG. 284.—Monobloc + Section (Plan).

There is a difference of 100 ampere-hours capacity between any two consecutive sizes of cell, the sizes ranging from 100 ampere-hours upwards. The smallest cell has the following capacities at the different rates of discharge:—

100 amp.-hours.	(10 hrs.	@ 10 amps.)	When discharged to 1·8 volts.
90 „ „	(6 „	15 „)	
75 „ „	(3 „	25 „)	
50 „ „	(1 „	50 „)	

Fig. 282 gives a good idea of the general appearance of this make of accumulator.

170. THE MONOBLOC CELLS.—When accumulators are used for traction, launch, and kindred work, the chief things which act against them are:—firstly, vibration, which in time loosens and dislodges the active material in pasted

FIG. 285.—Monobloc + and – Sections together.

FIG. 286.—Monobloc – Section.

plates of most kinds; secondly, buckling and distortion of the plates; and thirdly, breaking of the plates and connections from jolting. It is claimed that all these drawbacks have been overcome in the type of cell about to be described; which, as will be evident from the illustrations, is essentially different in construction from other cells.

Fig. 283 shows the positive section, or rather block, this being built up of punched corrugated sheets of lead piled

one on the other on a lead stand till the stack is of the requisite height; the sheets being "lead-burned" together and to the stand, at the corners; as well as to the terminal lug on the left. A plan of this block, showing the wave-formation of the sheets, is given in Fig. 284. The receptacles formed by the perforations in the sheets are occupied by the rods of the negative element (Fig. 286), a complete set being shown in Fig. 285.

The positive block, when built up as just described, is "formed" by a special variation of the Planté process, which results in a dense and closely-adherent coating of lead peroxide. As the result of this "formation," the block is found to resist well the combined disintegrating effects of rapid discharges and vibration. It will be evident that the electrolyte has very free circulation throughout the cell. The negative rods or pencils (Fig. 286) are wrapped in perforated celluloid sleeves to prevent contact with the positive block; some of these sleeves being removed in the figure. The rods are constructed as follows:—Hollow pellets of some lead compound (such as lead chloride) are cast in the shape shown at *P*, *P* in Fig. 287; and these are placed one above the other in a mould, which holds them slightly apart. Molten lead is then run in to form the supporting rod *L*, *L*, and the washer-like flange pieces, *W*, *W*, *W*. The pellets are then reduced by a special process to spongy lead.

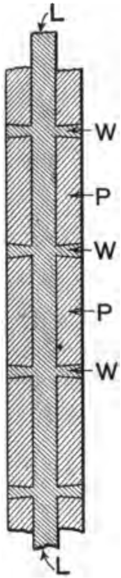

FIG. 287.—Section of Monobloc-Rod (half-size).

There are twenty-eight listed sizes of these cells. These vary, in capacity, from 33 to 800 ampere-hours, with maximum discharges of from 18 to 620 amperes; in outside dimensions, (ebonite containing-box) from $3\frac{1}{2}$ in. $\times$ $3\frac{1}{2}$ in. $\times$ $9\frac{1}{4}$ in. to $26\frac{1}{2}$ in. $\times$ $10\frac{1}{4}$ in. $\times$ 14 in.; and in weight—including acid—from 10 to 300 lbs.

***171. Private Generating Installations.**—Numerous large buildings and private residences are fitted with their own generating plant, or as the technical man would say, they have their private plant or private installation. Such "plant," by which rather expressive term is meant any collection of fixed machinery, nearly always comprises one or more engines and dynamos, and a battery of "accumulators" or secondary cells. Gas-engines are generally used when it is possible to do so, *i. e.* when gas is available; and turbines when a constant supply of water is to be had. Otherwise, oil or steam-engines are employed.

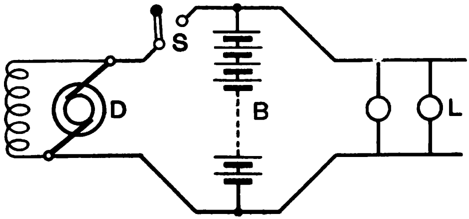

Fig. 288.—Diagram of simple Dynamo and Accumulator Arrangement.

Fig. 288 shows, in a very elementary manner, the way in which the shunt dynamo *D*, battery *B*, and lamps or other appliances *L*, are interconnected. When *D* is charging *B* it also supplies whatever current is wanted by *L*. When *D* is switched off at *S*, *L* derives current from *B* alone. In practice, of course, various regulating and other devices

have to be included in the circuit, as is explained in §§ 176 and 177.

172. ARRANGING AN INSTALLATION.—In arranging a private installation, the capacity of the battery must first be worked out, and afterwards that of the dynamo and engine. This is not quite such an easy matter as might at first appear. There are several points to be considered, which may be set out in order somewhat as follows:—

(*a*) Distribution pressure and number of cells.

(*b*) Largest current ever required.

(*c*) Average daily maximum current.

(*d*) Average daily consumption in watt-hours.

(*e*) No. of hours per day available for charging.

(*f*) Whether charging will be going on at the times of greatest demand or not.

173. NUMBER OF CELLS REQUIRED.—The number of cells depends upon the pressure adopted, there being, roughly speaking, half as many cells as volts on the circuit; each cell, it will be remembered, giving about 2 volts. For a given output in watts at, say, 200 volts, the cells would have to be twice as numerous as, though only half the size of, those necessary were the pressure 100 volts. Generally speaking, the less the number of individual cells the better. For very small installations, a distribution pressure of 50 volts might be employed; 100 volts being the usual pressure for installations of average size. It is only in the case of very large buildings, where the cost of wiring is a serious item, that pressures of 200 volts or so would be considered necessary.

As explained in § 161, the E.M.F. per cell starts at about 2·2 volts, and gradually falls during discharge to

1·85 volts. It is thus necessary to have spare cells in every battery, so that the P.D. between the leads may be kept up by means of a regulating-switch.

The least total number of cells for any supply pressure, may be got by dividing the pressure by the minimum P.D. per cell, *i.e.* 1·85 volts. The numbers for the ordinary supply voltages are then as follows:—

Supply Pressure.	50 volts.	100 volts.	200 volts.	240 volts.
Least no. of cells.	27	54	108	130

The above are the minimum numbers of cells that can be used with any given pressure, and these will only suffice when the lamps, etc., are close up to the battery. In the case of a country mansion, for example, where the engine- and battery-rooms are usually some distance away from the house, and the lamp circuits are long, there will be an appreciable drop of pressure in the mains from the cells to the distribution-board, and from the latter to the lamps. In such cases, 3 cells extra should be allowed for every 5 volts drop, or say 1 cell for every $1\frac{1}{2}$ volts drop. Then, further, an extra cell or two is generally added to provide for the event of a cell being incapacitated, and having to be cut out of the battery for repair.

In large installations it is a frequent practice to have two batteries connected in parallel, as the cells are then less unwieldy. Another advantage of this arrangement is, that one of the batteries may be cut out altogether for cleaning or repairs, without any interruption of the supply. This can only be done at times of light load, however,

such as during the summer months, unless the dynamo be kept running continuously to supplement the other battery.

174. Capacity of Cells.—Each size of cell has a certain maximum discharge rate which must never be exceeded, and a careful approximation must be made as to the maximum current that will ever be required. The cells must be of such a size as to be able to furnish such current, unless at times of heavy load the dynamo can be worked in conjunction with the cells. A more precise way of putting the matter is to say that the size of the cells is governed by the largest current they will ever have to furnish without the help of the dynamo, as well as by the average rate and duration of discharge.

When the dynamo is working with the cells, the former supplies most of the outer circuit current; the battery acting as a "pressure-steadier," and receiving a charging current meanwhile. If the dynamo is kept on after the cells have been fully charged, then the latter help to supply the lamps. If the dynamo can always be kept running while the majority of the lamps are on, the capacity of the battery need only be comparatively small. Very often, however, the charging is done in the day-time, the battery having to run all the lamps, etc., at night-time unaided. Then the capacity of the battery must be comparatively large.

In estimating the maximum current ever required under ordinary conditions, it should be remembered that only a portion of the total number of lamps will ever be alight at once. The proportion differs according to the class of building. In a works or factory, most of the lights would be "on" during working-hours. In a bank or block of offices, perhaps from nine-tenths to three-fourths

of the lights may be burning at once. In a dwelling-house, probably only about half the lights would ever be required at one and the same time. If there are motors and heaters, account must be taken as to whether they will usually be run in the day-time or at night-time; *i. e.* at a different or at the same time as the lamps. In computing the current for glow lamps, it is best to assume an outside efficiency of 4 watts per candle, rather than the often imaginary one of $3\frac{1}{2}$ or 3 watts, it being remembered that the current taken by lamps increases as they grow older (Chap. I.). With regard to motors, only the normal running current need be considered, not the starting current (§ 114). Needless to say, this rough calculation must be worked out for winter conditions, when there are the greatest number of dark hours in the twenty-four. To cope with any very exceptional demand, the dynamo can be run to help the battery.

It is better for the battery to have too large than too small a capacity. In the first case, the hours of charging can always be curtailed if there is not much drain on the cells. In the second, the charging hours may have to be inconveniently prolonged in order to keep the battery in proper condition. The subject of capacity is further dealt with in § 186.

175. Size and Type of Dynamo.—The P.D. of the dynamo must be at least 2·5 volts for every cell in series in the battery. Thus, taking the different pressures given in § 173, and adding 1, 2, 3 and 4 cells respectively, to compensate for drop of pressure and for "spares," the minimum dynamo P.Ds. would have to be as follows :—

Circuit Pressure.	50 volts.	100 volts.	200 volts.	240 volts.
No. of Cells.	28 (1 cell extra)	56 (2 cells extra)	111 (3 cells extra)	134 (4 cells extra)
Minimum Dynamo P. D.	70 volts.	140 volts.	278 volts.	335 volts.

It does not matter if the dynamo P.D. somewhat exceed these figures; such indeed had better be the case, so as to be on the safe side. The minimum current to be given by the machine, if it is simply to be used in charging the battery, would be equal to the maximum charging current that could be taken by the cells. If, on the other hand, it will be required to charge the cells and supply current to the outside circuit at the same time, the extra current must be carefully approximated and taken into account.

Having thus got the P.D. and maximum current required from the dynamo, the product of these will give its electrical output in watts. Reducing this to horse-power and dividing by the commercial efficiency of the machine will give us the power required from the engine. The latter, however, should be rated a little higher than this, to make up for the loss in belting, and so as to have spare power in hand to compensate for any lessening in efficiency on the part of the engine.

For reasons given in § 7, a battery-charging dynamo must either be shunt-wound or else separately excited; and it is also sometimes of advantage to use a 4-pole or multipolar machine, as the speed of such is generally less than that of 2-pole dynamos, and they take up less floor-space.

On the other hand, there is the multiplication of brushes to be considered, 4- and 6-pole machines being seldom connected now-a-days for two sets of brushes, as was formerly the case. Besides the lessened wear and tear of bearings and commutator, another advantage of slow-speed machines is that they can sometimes be coupled direct to their engines; and belting, with its attendant loss of power, dispensed with. A Crossley gas-engine, with an 8-pole dynamo coupled direct to it, is illustrated in Chap. *IX.*

In large installations it is best to have two or more dynamos, each with their separate engine; and in some cases it would be thought necessary to put down a spare generating set. By having separate and spare dynamos, the chance of total breakdown is avoided; and it is possible to effect repairs to any one set, while the other or others are charging the accumulators.

*176. PRIVATE GENERATING INSTALLATION.—The interconnection of dynamos and accumulators, and of the switching and regulating apparatus used therewith, may be effected in a variety of ways, which depend upon the size and character of the installation.

Fig. 289 shows the simplest possible diagram of connections. Here *Dy* is the dynamo, *F* its field coil, and *R* a shunt-regulating resistance by means of which the E.M.F. of the machine may be adjusted as required. *R* should have a stop *S* to prevent the field-circuit being broken. *B, B* represents the battery, with the middle cells left out to simplify the figure. Those at the left-hand end are connected to multiple-way charge and discharge switches *C* and *D*, the former being joined-up with one pole of the dynamo, and the latter with one of the mains

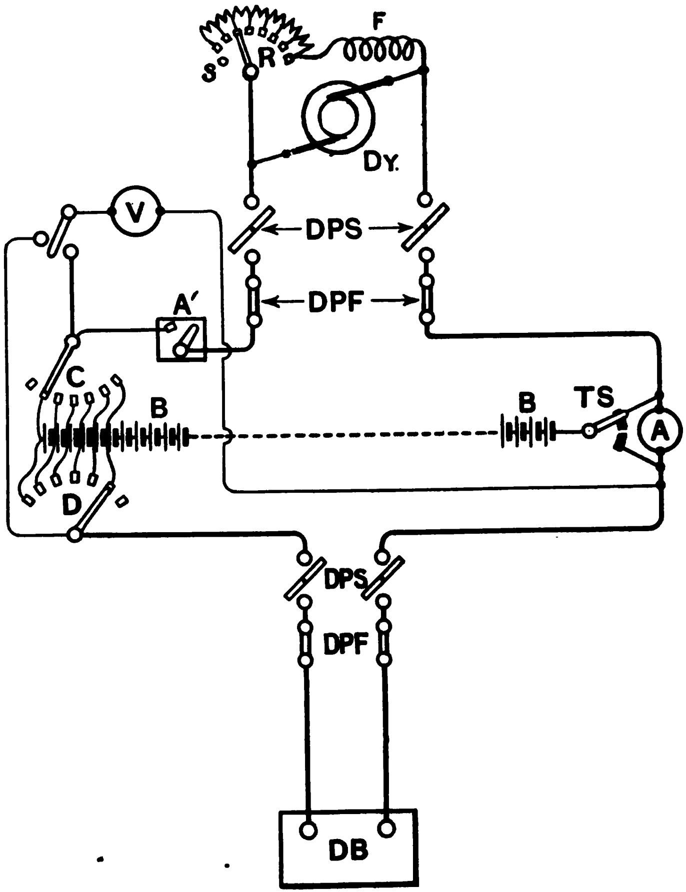

FIG. 289.—Simple Dynamo-Accumulator Installation.

running to the distribution-board *D B*. *A* is an ammeter permanently connected on one side with the dynamo, and on the other with the service mains, and through a 2-way switch *T S* with the right-hand end of the battery. When this switch is on the bottom contact, *A* indicates the current from the dynamo; while if it be on the top contact, *A* shows the current passing to the lamps, etc. The two "ways" or contacts of the switch are purposely put close together, so that the battery circuit shall not be broken in moving the lever from one to the other. The current from the dynamo is controlled by a double-pole switch and fuse at *D P S* and *D P F*; and similar appliances are placed at the point where the service cables branch off to the main distribution-board *D B*. The voltmeter *V* is permanently connected to the ammeter end of the circuit, and through a 2-way switch with either the charge or discharge side of the battery. In the first case it indicates the P.D. at or near the terminals of the dynamo, and in the second the P.D. at the terminals of the supply circuit. *A′* is an automatic switch which closes the circuit when the dynamo P.D. rises sufficiently above that of the battery; and breaks it if from any cause the generator P.D. should fall below that of the battery. Apparatus for this and kindred purposes are described in Chap. II.

As the end cells become charged, or as the P.D. of the battery rises, the cells under charge may be cut out one by one by means of the switch *C*. *D* is for the purpose of regulating the pressure at the distribution-board, fewest cells being in circuit when the dynamo is charging the battery, or when the latter is fully charged: and extra cells

being switched in as the P.D. of the battery falls during discharge.

The number of contacts on the switches *C* and *D*, and the number of cells between each pair of contacts, depends upon the pressure employed, and the number of extra cells in the battery. The switch contacts usually number 4, 6, 8, or 10; and 1, 2, 3 or more cells may be connected between neighbouring contacts. In Fig. 289 there is one cell between each step, but in Fig. 290 there are two.

In a 50-volt installation, or in a small 100-volt one, 1 cell between each contact of 4-way switches should suffice. With a fairly large 100-volt installation, or in the case of a 200-volt one, the number of contacts or "steps" on the switches must be increased, and 2 or even 3 cells connected between each pair. It is better, however, to keep the number of cells between each contact down to 2 or 3 at the most, as this enables better and less jerky regulation of the pressure to be effected.

177. Private Generating Installation (*continued*).—Fig. 290 gives a more elaborate circuit diagram in which everything that would be necessary in an installation of average size is included. Here *Dy* is the dynamo with its field coil *F*, and shunt-regulating rheostat *R* The leads from the dynamo pass through a double-pole switch and fuse *D P S* and *D P F*. On the + side, say, the main from the dynamo passes through the bottom contact of the 2-way switch *T W S*, and the automatic cut-in and cut-out *A*, to the charge switch *C*; while the − main runs to the battery and the main distribution-board *M D B*, the cables leading to the latter being controlled by a second double-pole switch and fuse, *D P S*, *D P F*.

The circuit at the negative end of the battery, before it

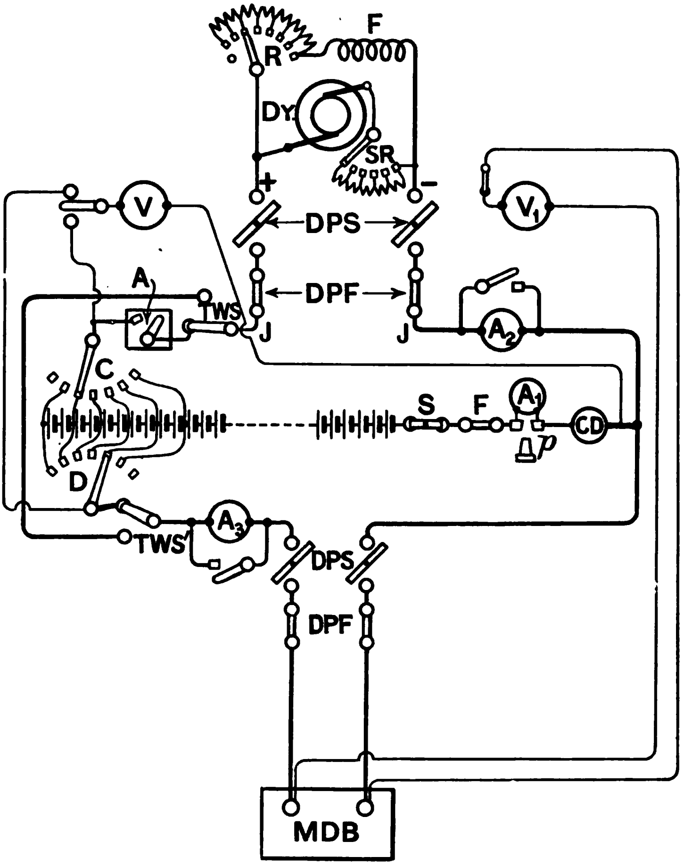

FIG. 290.—Dynamo-Accumulator Installation.

joins the mains from the dynamo and distribution-board,

has connected in it a single-pole switch *S*, and fuse *F*, ammeter A_1, and current-direction indicator *C D*. *S* enables the battery to be disconnected altogether at that end, *F* is a safeguard against over-charging or -discharging, A_1 shows the actual current passing, and *C D* whether the battery is charging or discharging. *F* may be replaced by an excess-current alarm, a form of which is illustrated and described in Chap. **II.**; and *C D* may be dispensed with if the needle of A_1 have its zero in the centre of the scale, and move to either side according to the direction of the current. A_1 may be put in or out of circuit by means of the short-circuiting plug *p*, or a switch may be used instead. The other two ammeters, A_2 and A_3, indicate the current in the dynamo and supply circuits respectively; and they may be thrown in or out of circuit by means of the adjacent switches. *D* is the discharge switch, which is connected through a 2-way switch *T W S′* with the supply circuit. By means of *T W S* and *T W S′*, *C* and *D* and the battery may be entirely disconnected, and the dynamo made to supply the demand by itself. This is useful when the cells need seeing to, and the supply cannot be stopped altogether.

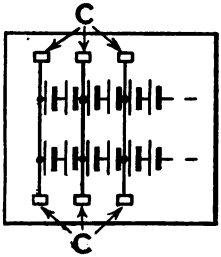

FIG. 291.—Accumulators in Parallel.

The voltmeter *V*, by means of the 2-way switch at its side, may be joined-up to either the dynamo or the supply side of the battery; while V_1 is connected straight to the bus-bars of the main distribution-board, and so indicates the pressure close to the lamps, etc. V_1 is generally

left always in circuit, so that any variation of pressure may be immediately noted, and compensated for by means of *D*.

S R is a starting resistance for use when the dynamo is belted to a gas-engine, and the accumulators are employed to start the latter, by temporarily "motoring" it (§ 182).

When two batteries in parallel are employed, the connection of the cells to the charge and discharge switches would be as in Fig. 291, where *C*, *C* are a few of the contacts of the switches.

Sir David Salomons has designed very ingenious self-acting apparatus for regulating the charging of the battery and the pressure at the lamps; but such would be too expensive, and probably also too complicated, for ordinary use.

Supposing there were two or more dynamos instead of one, these would each be connected through separate D.P. switches, fuses, and ammeters to the circuit at *J*, *J*.

Very large private installations partake of the character of small central stations, and use is sometimes made of a battery-charging booster, as explained in § 181.

*178. CHARGE AND DISCHARGE SWITCHES, OR BATTERY REGULATORS.—A 5-way S.P. switch for this purpose was illustrated and described in Chap. II. In that form it will be observed that the gap between the contacts is greater than the width of the switch arm. This is necessary to prevent the short-circuiting of a cell or cells in changing from one contact to another; but as a consequence, there is a momentary blink in the lights at the moment of switching cells in or out on the discharge side unless the switch is manipulated very quickly indeed.

There is also a certain amount of sparkwear when the switch is moved. To do away with both blinking and sparkwear, some such arrangement as that illustrated in Fig. 292 is adopted; the apparatus therein shown being a 6-way combined charge and discharge switch. Fixed on the side of the main contact arm, but insulated therefrom, is an auxiliary contact *A*, electrically connected with the main contact by a short coil *W* of high-resistance wire.

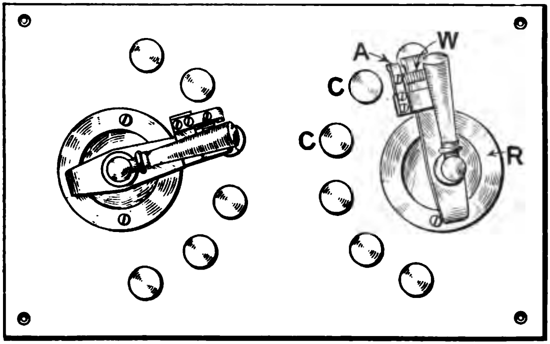

Fig. 292.—Radial-type Accumulator Switches.

The distance between the contact studs *C*, *C*, etc., is such that, in moving the switch arm from one to the other, the circuit is never actually broken; the cell or cells between two adjacent contacts being momentarily "shorted" through the wire *W*. Such does not amount to an actual short-circuit; and if the switch arm should be left in the intermediate position, *W* would speedily heat up and fuse before much damage could be done to the cell. A good point about this switch is that the circuit is completed across the rubbing contact *R*, and not through the

spindle and its sleeve, as in some patterns. The objection to the latter arrangement is that the contact is not very good, and that it cannot be easily got at for cleaning purposes.

Another form of radial accumulator switch is shown on the switchboard in Fig. 295, and in this also it will be seen that the switch spindle does not form part of the circuit.

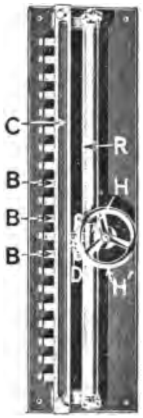

FIG. 293. — "Straight"-type Battery Regulator (Moy).

Fig. 293 depicts a "straight"-type of accumulator switch, or battery regulator as it is otherwise termed. The cells are connected up to the contact blocks *B*, *B*, *B*, etc., and in front of these is mounted a circuit bar *C*, which is connected up to the charging or discharging circuit as the case may be. Contact between any block *B* and the bar *C* is made by a double brush *D*, the holder *H* of which slides on and is moved up or down a rack-rod *R*, by means of a hand-wheel and pinion *H'* carried by *H*. This form enables a large number of contacts to be compactly arranged.

A battery regulator has been devised in which the short-circuiting resistance is quite separate from the switch, and thus may be made of any required value without rendering the switch unwieldy. The reader should exercise his ingenuity in sketching out such a switch for himself.

Sometimes, after a regulating switch has been fixed, it is found that there are not a sufficient number of "stops" for efficient regulation on the discharge side. A second switch may then be joined up in series with the first, in

the manner indicated in Fig. 294; the last "stop" *S* of the first switch being connected to the contact lever of the second. The cells are then rearranged as required between the increased number of "stops."

179. ACCUMULATOR SWITCHBOARDS.—Switchboards for private installations with accumulators naturally vary very much in design and arrangement.

A simple form of such is illustrated in Fig. 295. The dynamo is connected through the D.P. switch and fuses in the left-hand bottom corner, the + lead passing up to the left-hand ammeter, then to the S.P. fuse on the left-hand side of the 2-way switch, whence the current is led through the automatic cut-in and cut-out in the centre of the board, to the charging switch on the left. A branch connection from the S.P. fuse is taken to the left-hand contact of the 2-way switch, the right-hand contact being connected through the right-hand ammeter with the discharging switch on the right. The 2-way switch-arm is joined up to one of the poles of the D.P. switch and fuse on the right, to which the lamp leads are connected. One end of the battery is connected to the regulator switches, and the other to the S.P. fuse on the right of the 2-way switch; the other terminal of this fuse being connected to the – side of the D.P. dynamo switch, and also to the other terminal of the D.P. lighting switch. The ammeters, it will be observed, have short-circuiting plugs, and the volt-meter

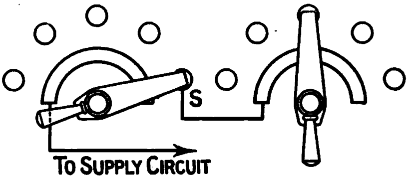

FIG. 294.—Accumulator Switches in Series.

in the centre has a switch which enables it to be connected to the dynamo, battery, or supply circuit at will. This arrangement is slightly different from that in Fig. 289. Thus there are two ammeters, one in the dynamo and the other in the discharging circuit, and a S.P. fuse

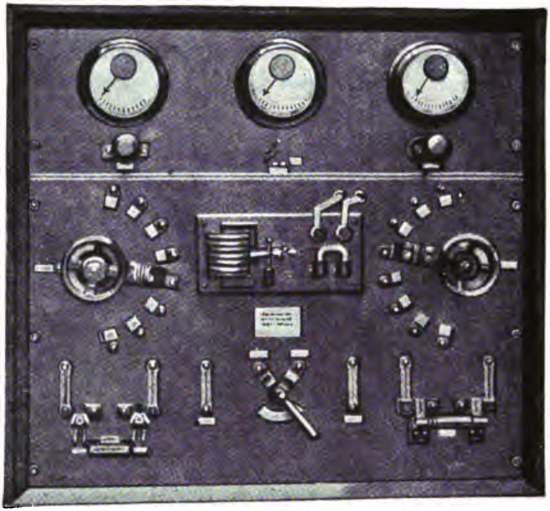

Fig. 295.—Accumulator Switch-board (Spagnoletti & Co.).

takes the place of *TS* in Fig. 289, while another is connected in series with the automatic cut-in and cut-out. The 2-way switch in Fig. 295 occupies much the same position as *TWS'* in Fig. 290.

180. Regulating-Cells.—Unless it should happen, which is only now and then the case, that the charge and discharge switches of the accumulator regulator are

on corresponding contacts, one or more cells have to carry the current passing to the supply circuit as well as that used in charging the battery; and this excessive current is detrimental to them. Fig. 296 illustrates this point. Here we have the end or regulating-cells of a 53-cell battery connected to the charge and discharge switches *C* and *D*. In the position shown, *C* is on the end cell, and *D* on cell No. 49; consequently, cells 50 to 53 have to carry the current flowing to the distribution-board, as well as that going through the whole battery.

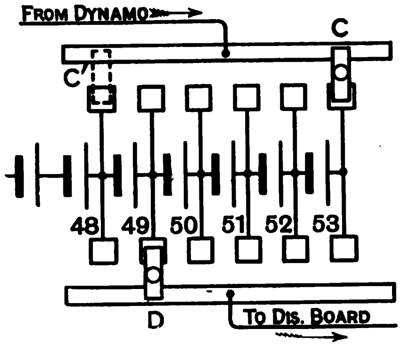

FIG. 296.—Regulating Cells.

In those cases where the generator is always run with the battery at times of heavy load, and the latter when left to itself has only a light load to cope with, the battery is comparatively small in capacity; and the current passing through those intermediate regulating-cells, when the dynamo is running, is considerably in excess of the normal charging current. In such a case, with the capacity of the battery small as compared with the maximum demand, rapid deterioration of the end cells, which would otherwise ensue, can be prevented by having them of larger size than the rest of the battery.

Care should be taken that the charging switch is never placed on a lower cell than that on the discharge side,

for if such should happen, the current passing to the distribution-board would flow through the intermediate cells in the discharging direction, and would help to discharge them. Thus, referring to Fig. 296, if the charging switch were in the dotted position C', the current flowing from the dynamo to the distribution-board would pass through cell No. 49 in the discharging direction; and, if continued for any length of time, would bring down the voltage of the cell and sulphate it to a harmful degree.

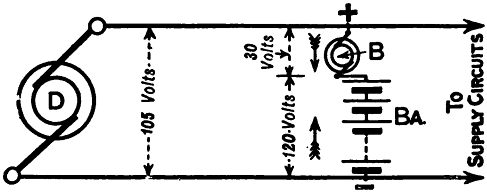

FIG. 297.—Simple Battery-Charging Booster Circuit.

181. BATTERY-CHARGING BOOSTER.—A *booster*, as is more fully explained in the next chapter, is a small generator driven by a motor; and it is used to add or subtract volts to or from a circuit, as may be required. When employed for battery-charging purposes, it enables all the cells to be charged from the main dynamo, even though the P.D. of the latter may be less than that of the battery. Thus, the dynamo may be supplying the bus-bars and the supply circuits at a pressure of, say, 105 volts, and at the same time, with the help of a booster, charging a battery whose E.M.F. is considerably higher than this. The advantage of such an arrangement is that the main dynamo

(or dynamos) need not generate a greater P.D. than is required on the bus-bars, and a saving of power results.

To understand the action of a booster when used for this purpose, let us refer to Fig. 297. Here *D* is the main dynamo supplying current to the battery, and to the supply circuits, at a pressure of, say, 105 volts. *B* is the booster, or auxiliary dynamo as it may be termed, this giving let us suppose, a pressure of 30 volts in the opposite

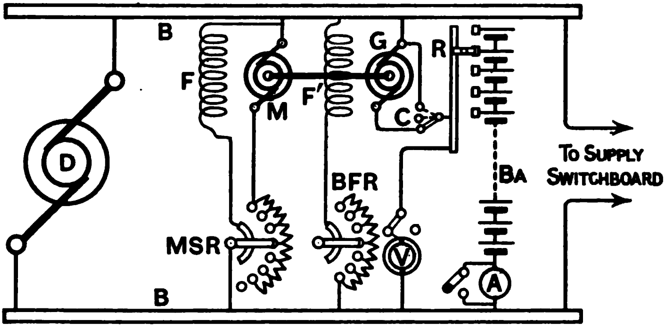

Fig. 298.—Dynamo-Booster-Accumulator Circuit.

direction to the battery pressure. *B* is driven by a motor (not shown) connected across the bus-bars. *BA* is the battery, which, when all the cells are in circuit and nearly charged, gives an E.M.F. of, say, 120 volts counter to that of the dynamo *D*.

The action of the booster is to cancel some of the E.M.F. of the battery. Thus, regarding the battery circuit alone, we have an E.M.F. of 120 volts in one direction due to the battery, and one of 30 volts in the other due to the booster. The resultant E.M.F. opposed to the bus-bar

pressure will thus be 90 volts, so that current will flow through the battery in a charging direction under a pressure of 15 volts.

There are several ways of combining a booster with a battery; one of the simplest, which possesses the advantage that only one regulating switch is required, being that diagrammed in Fig. 298. Here *D* is the main dynamo, with its field circuit omitted; and *B*, *B*, are the bus-bars. *M* is a motor direct-coupled to the booster-generator *G*, as indicated by the connecting line. This way of illustrating a motor generator diagrammatically, by the way, is shown apart in Fig. 299, and should be remembered. *M* takes its current from the bus-bars, and its speed (and consequently the boosting volts generated by *G*,) are regulated by the motor-starting switch and regulating resistance *M S R*. *F* and *F′* are the field coils of *M* and *G* respectively. *F′* may be joined across the bus-bars through the booster field regulator *B F R*, the latter affording another means of adjusting the E.M.F. of *G*: or the two armature windings of *M* and *G* may be wound on a common core, and rotated in a single field due to *F* (Fig. 334). *BA* is the battery, the end cells of which are joined to a single regulating switch *R*. An ammeter *A* shows the current passing through *BA*, as well as its direction, *i.e.* whether the battery is charging or discharging; while the voltmeter *V* indicates the pressure between the negative bus-bar and the battery-regulating switch. *C* is a 3-way switch, which, in the position shown, puts the booster in circuit; otherwise the booster is put out of circuit, and *R* and *BA* are connected directly to the positive bus-bar, or entirely disconnected therefrom.

Suppose the dynamo is working, and the battery is to be

charged. $B\,F\,R$ is placed so as to exclude all extra resistance from the circuit, C is put into its intermediate or off position, so as to cut the battery out entirely, and $M\,G$ is started by means of $M\,S\,R$, it being run up to nearly full speed so as to generate full voltage at G. R is then placed so as to include all the cells in circuit, and C is put on to the lower stop. The charging current, as indicated on A, is then adjusted to its proper value, by regulating the speed of the motor-generator by $M\,S\,R$, or by varying the resistance at $B\,F\,R$.

When the battery is fully charged, $B\,F\,R$ and R are adjusted until A indicates no current; the circuit is then opened at C, and M and $M\,S\,R$ gradually switched off. The pressure indicated on V being then adjusted by means of R to that required by the circuit, BA is switched direct on to the bus-bars at C, and D if need be may be stopped.

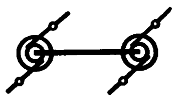

FIG. 299.—Symbol for Motor-Generator.

This arrangement would be too expensive for ordinary small private installations, but in large ones will be found to possess many advantages, and to be economical. It is possible to do away with the regulating switch altogether, a reversible booster—which works automatically *against* or *with* the battery—being employed, as explained in §§ 227 and 228.

*182. WORKING HINTS.

(*a*) If there be any doubt as to the polarity of the dynamo, it may be tested by joining some kind of electrolytic cell (§ 151) in series with a lamp across its terminals; or, in a simpler way, by means of *pole-finding paper*. This latter is a chemically prepared paper which,

when moistened and laid between the terminal wires, so as to form part of the circuit, changes colour at one of the poles.

(*b*) The + pole of the dynamo is connected to the + pole of the battery.

(*c*) When the dynamo is driven by a gas-engine that requires help in starting, the current from the accumulators may be used to run the dynamo as a motor, and thus give the necessary initial turns to the engine. If this method be resorted to, some means must be provided, as at *S R* in Fig. 290, for putting resistance in the armature circuit; else the latter would probably be damaged by the large initial starting current flowing through it from the battery. When the engine has once started, the cells should be cut off at *D P S*, and the resistance at *S R* reduced to zero.

(*d*) After the dynamo has been started, all the resistance should be cut out at *R* (Fig. 290), and time given for it to get up its maximum E.M.F. (as ascertained by *V*) before connecting it with the cells at *A*.

(*e*) In stopping the dynamo, the cells must first of all be switched off at *D P S*, the gas supply cut off from the engine, all resistance inserted first at *R* and then at *S R*, and lastly—when the rotation has nearly ceased—the brushes should be raised from the commutator. If the brushes be raised while the F.M. is fully excited, the inductance of the latter will cause sparkwear and throw stress on the insulation of the field coils. The brushes must be raised before the machine stops, to prevent their bending, should the engine take a part turn backwards, and their edges catch in the commutator. With end-on brushes this precaution is unnecessary.

(*f*) For reasons given in § 180, the charging switch of a battery regulator should never be on a lower contact (or number of cells) than the discharging switch.

*183. HINTS ON THE CARE OF CELLS.

(*a*) Each cell should stand in a wooden tray filled with sawdust to absorb moisture; and each tray must stand on four glass *oil insulators* of the pattern shown in perspective and in section in Fig. 300. From the right-hand figure it will be seen that each insulator is in two parts, the lower being in the form of a cup and containing resin oil, and the upper resting in the oil and forming a dust-pro-

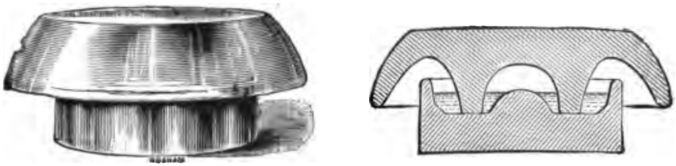

FIG. 300.—Oil Insulators (E.P.S. Co.).

tecting hood over it. Sheets of lead sometimes take the place of the trays (§ 168).

(*b*) The sulphuric acid for the cells must be free from impurities, and must be mixed with pure water. The acid must be added to the water gradually, with continual stirring, in the proportion of about 1 part of acid to 5 of water. The exact proportion is such that after the liquid has cooled down, its specific gravity as indicated by a hydrometer (§ 184) is 1·180 or 1·190. If the sp. g. (specific gravity) be too high, more water must be added; if too low, more acid. If the water be hard it should be boiled before use.

(*c*) When fresh liquid is added to make up for the loss from the cells by evaporation, it must be in the form of pure water. The electrolyte must always cover the tops of the plates.

(*d*) The voltage of a cell, as indicated by a reliable cell-testing voltmeter, should never be allowed to fall below 1·85 volts. This test must be made when the battery is discharging. If made during charging the voltmeter will indicate too high a value.

(*e*) The condition of a cell is best indicated by a hydrometer. When discharged as far as permissible, the sp. g. of the electrolyte falls to about 1·170; when fully charged, it rises to 1·200 or 1·210.

(*f*) The voltage and sp. g. of each cell should be taken at least once a week. Defects will thus be detected early, and should be remedied without delay.

(*g*) When a battery is first set up it must be charged directly, and for from 30 to 40 hours without intermission.

(*h*) Each type of cell has different charging rates or currents, which must be ascertained. It is best to charge cells slowly at their low rate than quickly at their high rate.

(*i*) When a cell is fully charged the electrolyte becomes "milky," owing to the presence of innumerable bubbles of gas that the plates will not absorb. If the charging rate be too high, however, cells will sometimes milk before they are fully charged.

(*j*) A battery must be charged to the "milky" state once or twice every week.

(*k*) Any cell which refuses to "milk" in company with the others has probably something wrong with it. It must

then be carefully examined to see if any pieces of paste, scab, or other body have lodged between the plates; and if so, such must be removed. If the plates are touching, the section must be taken out directly, and the plates straightened. To restore the cell to good condition, it must only be in circuit with the rest of the battery during times of charging. The milky state will indicate its recovery.

(*l*) The maximum discharge rate of a battery must never be exceeded.

(*m*) A cell or cells must never be short-circuited.

(*n*) The connections between cell and cell must be kept perfectly clean.

(*o*) A battery must not be allowed to remain for any length of time in a discharged or partly discharged condition. If this happens, a dense coating of lead sulphate will gradually form on both plates, and will not easily be got rid of by charging, as it is a bad conductor. It was explained in § 155 that the sulphate forms in the ordinary discharge of the cell, but this is only a very thin coating, which soon disappears on recharge.

(*p*) When cells are in good condition and fully charged, the positives should be of a clear reddish-brown or chocolate colour, and the negatives bluish-grey.

*184. THE HYDROMETER AND ITS USE.—A hydrometer usually takes the form of a long glass bulb, which, when immersed in a liquid, indicates its specific gravity on a scale on the stem of the instrument, the reading being taken at the level of the surface of the liquid. The greater the density of the liquid the higher will the hydrometer float in it.

The specific gravity of a liquid is its density, or the

weight of a given volume of it, as compared with that of pure water, which is taken as unity. In other words, the density of pure water is 1, as will be seen if a hydrometer be floated in it, when the unit or thousand mark will be level with the surface of the water.

Sulphuric acid has a greater density than water. Consequently any solution of the acid in water will possess greater specific gravity than pure water; and the greater the proportion of acid the greater will be the density.

When a cell or battery is first put together, the solution of acid is made up with a sp. g. of 1·180 before being put into the cells. When the battery is in regular working, its condition as to being partly or fully charged affects the sp. g. of the electrolyte. This should be evident from § 155, where the symbols roughly indicate that the quantity of free acid in the solution is greatest when the cell is fully charged.

Thus it is that the hydrometer, sometimes termed *acidometer,* indicates "how much charge" there is in a cell.

There are various forms of hydrometer, four being shown in Figs. 301–304. That in Fig. 301 is of the ordinary type, the reading being taken on the graduated stem at the level of the liquid. The bulb and stem are hermetically sealed, the former being weighted with fine shot. With the Holden hydrometer (Fig. 302) a wooden scale is clamped on the bar of the cell, and adjusted so that its lower extremity just touches the surface of the liquid. The hydrometer is then floated in the latter, and the reading taken on the scale at the level of the top of the hydrometer stem. In the hydrometer shown in Fig. 303, the tube is open at both ends, and serves merely to contain four miniature *bead*

hydrometers, which are differently coloured and float at

Fig. 301.—Ordinary Hydrometer.

Fig. 302.—Holden Hydrometer. (D.P. Battery Co.)

Fig. 303.—Bead Hydrometer.

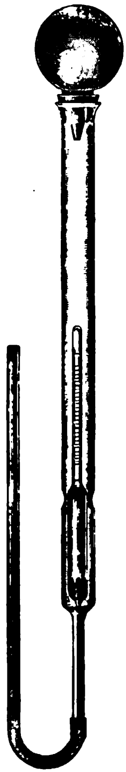

Fig. 304.—Hurst Enclosed Hydrometer. (E.P.S. Co.)

different densities, usually 1·105, 1·170, 1·190, and 1·200.

The containing-tube is dipped into the cell, and the liquid entering it causes one or more of the beads to float. In some forms the tube has a number of holes to enable the liquid to enter quickly. If there be only one hole, say, in the bottom of the tube, and this be a fine one, and the thumb be placed over the orifice at the top, the tube may be withdrawn with a quantity of the electrolyte, and the position of the beads noted before the liquid has time to leak out. This form is useful with cells in opaque boxes.

Fig. 304 shows another kind of hydrometer for use with cells in opaque boxes or in inaccessible positions. The hydrometer is enclosed in a glass tube having a hollow rubber-ball at one end and a rubber tube at the other. By squeezing the ball and inserting the end of the tube in the cell under notice, and then releasing the ball, a sufficient quantity of the electrolyte to float the hydrometer can be withdrawn from the cell, and its specific gravity noted. On again squeezing the ball, the liquid will be ejected from the tube.

The construction of cell-testing voltmeters (or cell-testers) and of cell-viewing lamps is referred to in Chaps. *VII* and **I** respectively.

It will be observed that the specific gravity values given above are very little over unity. In practice, however, it is a common thing to drop the decimal point and speak of specific gravities of 1105, 1170, 1190, and so on.

185. Arrangement of Cells for driving Electric Vehicles.—There are naturally a number of ways in which the cells and the one or two motors used to drive an electric automobile may be connected with the controlling-gear, but it must suffice if we give one example.

The electric victoria depicted in Fig. 305 is fitted with E.P.S. cells of the Faure-King type (§ 165), these driving a single motor which acts on the rear axle through cog reduction and differential gear. The vehicle is fitted with

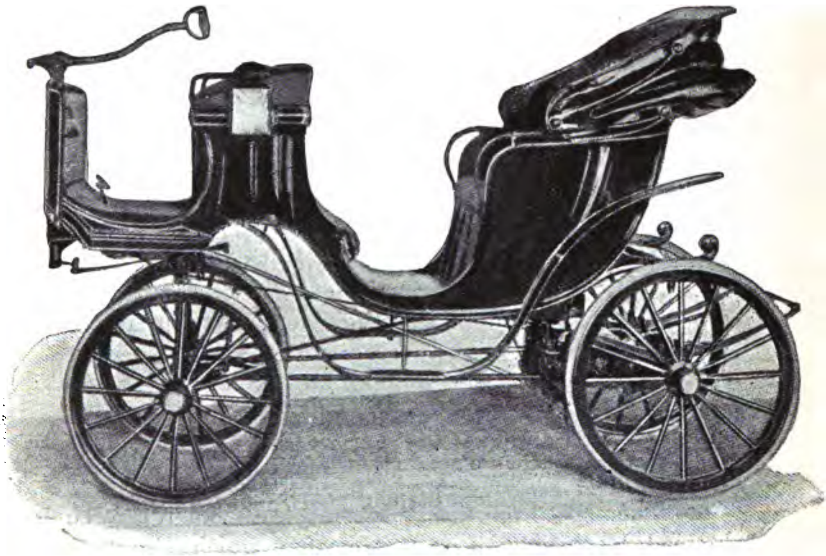

FIG. 305.—Electric Victoria (E.P.S. Co.).

three brakes, viz. a band brake, operated by the steering lever and acting on the motor axle; an electric brake similarly acting; and a shoe brake for the rims of the driving-wheels, actuated by a pedal. The whole weighs about 23 cwt.

The motor is bipolar and series-wound, giving a

maximum output of $2\frac{1}{2}$ h.p., and making 1,800 r.p.m. at full speed.

The lever in front of the driver performs the double operation of regulating the speed of the vehicle and of steering the same. Steering is effected by moving the lever to right or to left, this motion being communicated to the front pair of wheels; while for regulating the speed it is moved up or down. The lever has four driving positions, which alter the speed by varying the number of cells in series with the motor; there being 40 cells in all, divided up into four sections of 10 in each.

When the steering lever is raised to its highest point, the band brake is applied to the motor shaft. The next downward point releases the brake. With the lever at its third point, the four sets of cells are put in parallel, the motor being thus supplied at 20 volts. At the fourth position the cells are arranged in two parallel sets of 20 in series, the motor then running at 40 volts. At its lowest point the lever puts all the cells in series, thus applying 80 volts to the motor, and the resultant speed is about 12 miles per hour.

A higher speed of about 15 miles per hour can be obtained by means of a foot button which shunts a portion of the field current through a resistance, the weakening of the field causing the motor to run faster (§ 117). The lamps for lighting the vehicle are worked off one set of ten cells.

186. CALCULATIONS.

(*a*) GIVEN THE REQUISITE CHARGING CURRENT AND PARTICULARS OF THE BATTERY, TO FIND THE NECESSARY P.D. AT THE TERMINALS OF THE DYNAMO.—A battery of

54 cells in series, each with an internal resistance of 0·0025 ohm, requires a charging current of 80 amperes. What must be the P.D. at the terminals of the dynamo, the cables connecting the latter with the battery having a total resistance of 0·05 ohm?

Assuming that the back E.M.F. of each cell (§161) will reach a maximum of 2·2 volts, the total E.M.F. of the battery will be $2·2 \times 54 = 119$ volts.

When there are two opposing E.M.Fs. or pressures in a circuit, the resultant pressure is the difference between them. Thus if we denote the dynamo P.D. by E, the battery E.M.F. by e, the resistance of the battery and connecting leads by R, and the current by C, we have :—

$$C = \frac{E - e}{R}$$

or, $E - e = CR$

so that, $E = (CR) + e.$

Then :— $E = \left\{80 \times ([54 \times ·0025] + ·05)\right\} + 119$

$$= 15 + 119 = 134 \text{ volts.}$$

Thus the terminal P.D. of the dynamo must be at least 134 volts.

(*b*) TO FIND THE SIZE AND NUMBER OF CELLS NECESSARY FOR A GIVEN OUTPUT.—What number of cells in series will be required to run 150 60-watt glow lamps, and 12 5-ampere arc lamps, all in parallel; and to supply, in addition, 800 watts for motive and heating purposes?

It is to be assumed that only two-thirds of the total current required for all lamps, motors, and heaters, will ever be wanted at once. The supply pressure is to be 100

volts, and an extra 5 volts is to be allowed for drop in the mains.

The total current will be :—

		Amperes.
Glow lamps $(60 \div 100) \times 150$	=	90
Arc lamps 5×12	=	60
Motive and heating purposes $800 \div 100$	=	8
	Total.	158

Two-thirds of 158 is 105, this being the maximum current demand. The cells will therefore have to be of such a size as to be equal to a normal discharge rate of about 105 amperes; or less than this if the maximum current demand will only be put upon them occasionally. The necessary size of any given type may then be got from the maker's list.

The total pressure being 105 volts, and the minimum P.D. of each cell about 1·85 volts, the necessary number of cells will be $105 \div 1·85 = 57$ cells.

(*c*) TO FIND THE NUMBER OF LAMPS THAT MAY BE CONNECTED TO A BATTERY.

(i.) If a battery of 106 cells in series be used to supply current to glow lamps in parallel, each cell having 1·95 volts average E.M.F., and $0·0055\omega$ resistance, how many glow lamps, each requiring 200 volts and 0·4 amp., may be turned on at once?

(ii.) If two extra cells are put in series, how many more lamps may be used?

(i.) If n = number of lamps, the total current $= n \times 0·4$ amperes.

Total E.M.F. of cells − drop of volts in cells = terminal P.D.: or $106 \times 1{\cdot}95 - n \times 0{\cdot}4 \times 106 \times 0{\cdot}0055 = 200.$

$$\therefore n \times 0{\cdot}4 \times 106 \times 0{\cdot}0055 = 206{\cdot}7 - 200$$

Thus :— $$0{\cdot}233\, n = 6{\cdot}7$$

and :— $$n = 29 \text{ (approx.)}$$

hence 29 glow lamps may be turned on.

(ii.) In this case :—

$$\text{Total E.M.F.} = 108 \times 1{\cdot}95 = 210{\cdot}6 \text{ volts}$$

$$\therefore 210{\cdot}6 - n \times 0{\cdot}4 \times 108 \times 0{\cdot}0055 = 200$$

Thus :— $$n = \frac{10{\cdot}6}{0{\cdot}238}$$

$$= 45 \text{ (approx.)}$$

That is to say, 16 more lamps may be used.

Other examples of calculations relating to batteries will be found in Chapter **IV.**

CHAPTER XV.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Sketch and describe any apparatus for the electrolysis of water with which you are acquainted, other than that illustrated in § 149.

*2. Sketch some apparatus for the electrolysis of copper sulphate, and give theoretical reasons for the results obtained therewith.

3. Illustrate the theory of electrolysis (§ 152) by diagrams of your own, and explain the same.

4. State what ions are produced at the anode and kathode respectively during the electrolysis of the following electrolytes :—water, solution of sodium chloride in water, solution of copper sulphate in water, sulphuric acid, and hydrochloric acid.

5. What is Faraday's law regarding electro-deposition? How much caustic soda is produced per ampere hour, and how much lead, silver, and mercury (from mercurous nitrate) would be deposited per ampere hour? One coulomb evolves, say, 0·0104 [1] milligramme of hydrogen, and the atomic weights of sodium, lead, silver, and mercury, are respectively 23, 207, 108 and 200. [Ord. 1899.]

6. If 10,000 kilocoulombs are passed through cells arranged in series containing solutions of Cu_2Cl_2, $Hg_2(NO_3)_2$, $CuSO_4$, H_2SO_4, and NaCl, how much copper, mercury, hydrogen, and caustic can be obtained? [Ord. 1895.]

7. Describe the chemical actions going on when two lead plates are immersed in dilute sulphuric acid and connected to the poles of a continuous current dynamo. What is meant by *forming* plates? [Ord. 1890.]

8. Describe in detail the electro-chemical method of preparing calcium carbide, or aluminium. [Ord. 1900.]

*9. In what respects does a primary cell differ from a secondary cell?

*10. Prove that a secondary cell stores up chemical and not electrical energy.

*11. Explain, in as few words as possible, the construction and action of a simple kind of secondary cell.

*12. Explain clearly how, starting with two plain lead plates in dilute acid, repeated chargings and dischargings in opposite directions cause the gradual formation of spongy lead on the surface of both plates.

13. Distinguish between the capacity and the efficiency of a secondary battery.

*14. *Define*:—Electrolysis, "forming" of plates, pasted plate, separator, buckling.

15. Describe the mode for making a secondary battery, giving details of manufacture of the plates. [Ord. 1891.]

16. What are the advantages and disadvantages of the Planté and pasted plates for secondary cells? [Ord. 1895.]

17. How is an accumulator made, and how is it employed in

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[1] The original question wrongly stated this as $=0·104$.

practice? What are the various precautions that should be adopted in the use of accumulators, and what happens if these precautions are neglected? [Ord. 1901.]

*18. Sketch and describe some good form of accumulator, and explain how you would ascertain whether it was charged or discharged. About how much current may be taken from an accumulator per square foot of positive plate, and what occurs if the accumulator be discharged at a much higher rate? [Prel. 1899.]

*19. How would you find out which brush of a shunt dynamo should be connected with the positive terminal of a battery of accumulators in order that the battery might be charged when the dynamo was run at the right speed? [Prel. 1899.]

20. What kind of dynamo is best for charging accumulators, and why? [Ord. 1897.]

21. It is required to charge 55 accumulators (ordinary sort, with lead, etc., plates) whose ordinary rate of discharge is 100 amperes. There are available four dynamos of following sorts: (*a*) a series dynamo, 50 amperes at 130 volts; (*b*) a series dynamo, 100 amperes at 50 volts; (*c*) a shunt dynamo, 50 amperes at 130 volts; (*d*) a shunt dynamo, 100 amperes at 50 volts. Which one would you employ, and why? [Ord. 1896.]

22. Give the number of storage cells required for a 100-volt private house installation. Also state maximum charging voltage, and say how many cells must be connected with the regulating switch. [Ord. 1894.]

23. Sketch the arrangement of plant when a gas-engine, driving a continuous current dynamo, charges secondary batteries and lights incandescence lamps. How many cells are required, and what electromotive force must the dynamo have, if the lamps used are 100-volt lamps? [Ord. 1890.]

*24. In starting to charge a set of accumulators by means of an engine and dynamo, what precautions would you take after starting the engine before finally closing the connections between the dynamo and accumulators? [Prel. 1900.]

25. How should a gas-engine and dynamo be stopped so as to avoid both the bending-up of the brushes by the engine giving a portion of a turn backwards, and the stress on the insulation of the

field magnet winding by the brushes being raised while the field magnet is excited? [Ord. 1899.]

26. You are required to charge 50 accumulators in series from 100 volts constant pressure mains. Describe and sketch the kind of apparatus you would employ to do this. [Ord. 1898.]

*27. Show by means of diagrams how you would arrange an alarm circuit to operate when a storage battery becomes overcharged or overdischarged. [Prel. 1902.]

28. Make a diagrammatic sketch after the style of Fig. 289, but showing only the apparatus on the switchboard in Fig. 295. Fill in the connections between the different switches, fuses, etc., and show where the dynamo, cells, and supply circuit are joined up.

29. Show by means of a sketch how you would arrange on a switchboard the apparatus given in the circuit diagram in Fig. 289.

30. Alter the diagram of connections in Fig. 290, so as to include a battery-charging booster, and insert the necessary additional fuses and other accessory apparatus.

31. A compound-wound dynamo producing a terminal P.D. of 150 volts is used to charge 60 storage cells, each having an E.M.F. of 2·2 volts and a resistance of 0·001 ohm. If the leads joining the dynamo and cells have a resistance of 0·2 ohm, what will be the current generated? [Ord. 1897.]

32. Describe, with sketches, two well-known types of secondary cells, one suitable for central station work and one for traction, and point out in what respects they differ. [Ord. 1898.]

33. How would you vary the speed of a motor-car propelled with accumulators? What is about the minimum weight of accumulators necessary to develop 2 h.p. without damage to the cells, and how much per cent. of the energy put into the cells when they were charged would you expect the cells to give out in the propulsion of the motor-car? [Ord. 1901.]

CHAPTER XVI

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.), and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

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*187. TRANSFORMERS.—*Transformers* or *converters* are devices for changing the pressure or character of a current supply. Thus the ordinary *static* or *molecular transformer*, which has no moving parts, is used generally either to reduce or increase the pressure; or (as in certain polyphase

transformers, § 200) to change the character, of an alternating supply of electrical energy. The *rotary transformer* or *motor generator* is a combination of a motor and a dynamo (or alternator); and by means of such, any kind of supply of electrical energy may be changed either in pressure or in character, or in both. Thus a direct current may be transformed into a similar current at either lower or higher voltage, in which case the machine is termed a *direct-current transformer*. A direct-current supply may be also converted into an alternating-current one or *vice versâ*; or single-phase transformed into polyphase currents, or the

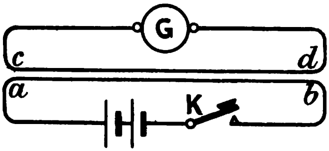

FIG. 306.

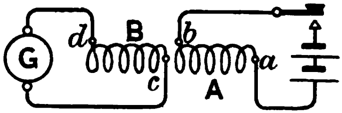

FIG. 307.

Induction of Currents.

reverse. *Step-down* and *step-up transformers* are respectively those which diminish or increase the voltage of the supply. When we add that there are several special modifications of both static and rotary transformers, it will be understood that under the single term "transformer" a great variety of apparatus and machines is comprised.

*188. PRINCIPLE OF THE STATIC TRANSFORMER.—The ordinary single-phase static transformer depends for its action upon the induction between two neighbouring but distinct electric circuits, which are interlinked with a magnetic circuit.

With apparatus arranged as in Fig. 306, when the

key K is depressed and a current is sent along $a\ b$, a momentary current is induced in $c\ d$: and when the current in $a\ b$ is stopped, another momentary current is induced in $c\ d$ in the opposite direction to the first induced current; these being indicated by the galvanoscope G. Thus, if the key be continually depressed and released, causing an intermittent current to flow in $a\ b$, it is clear that an alternating current will be induced in $c\ d$. For reasons given in § *61*, the reader will understand that the above effect will be much increased if the wires are coiled up as in Fig. 307; and still more increased if the

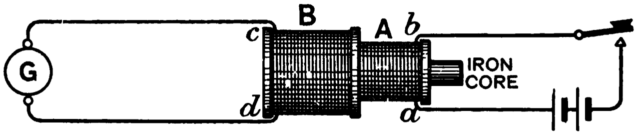

FIG. 308.—Induction of Currents.

coils A and B be inserted one within the other, and provided with an iron core in order to increase the number of lines of force, as shown in Fig. 308. This is the principle of the ordinary *induction coil*, which is a converter for transforming an intermittent direct into an alternating current.

The simplest form of static transformer is similar in construction to an induction coil, in that it consists of two separate coils wound upon an iron core; but it differs from it in having no contact-breaker or condenser. In Fig. 309, $I\ C$ represents an iron core on which are wound two distinct coils P and S, one of which, P, is called the *primary coil*, because it carries the *inducing current;* while the other, S, is termed the *secondary coil*, because it is the one which

has currents (or more correctly speaking—electro-motive forces) induced in it.

It should be perfectly clear, from what was said overleaf, that if an intermittent current be sent through the primary coil *P*, an alternating current will be induced in the secondary coil *S*. We shall now proceed to show that if an alternating current be sent through *P*, an alternating current will be induced in *S*. Referring again to Fig. 306, if a current is sent from *a* to *b*, a momentary current will flow from *d* to *c*; and when the current in *a b* is stopped, another momentary induced current will flow from *c* to *d*. But if the current in *a b* instead of being stopped is immediately reversed, the second induced current in *c d* will still flow from *c* to *d*, but will be much greater. Thus it is evident that an alternating current passing through the primary coil *P*, Fig. 309, will induce an alternating current in the secondary coil *S*.

FIG. 309.—Simple Open-circuit Transformer.

As might be gathered from Fig. 308, it is not absolutely necessary for the primary and secondary coils to be placed one within the other, so long as the lines of force set up by the primary coil are led by an easy path, such as a laminated iron core, through the secondary.

*189. STEP-UP AND STEP-DOWN TRANSFORMERS.—The usual duty of a static transformer is to induce a current in the secondary coil which shall have a greater or a less voltage than the current in the primary coil. The difference of pressure thus created or set up depends upon the

relative number of turns in the two coils. If the primary and secondary coils had exactly an equal number of turns, as in Fig. 309, the pressure of the current in the secondary would be practically the same as that of the current in the primary. If the secondary have a *greater* number of turns than the primary, as in a *step-up transformer*, then the pressure in the secondary will be greater than the pressure in the primary. On the other hand, if the secondary have a *less* number of turns than the primary, as in a *step-down transformer*, the pressure in the secondary will be less than that in the primary. In other words, the voltage induced depends upon the number of magnetic lines set up by the primary and the number of turns of wire which they cut in the secondary.

The current of course is not the same in the primary and secondary circuits. In a step-up transformer a large current at small pressure is converted into a smaller current at higher pressure. In a step-down transformer it is just the reverse, a small current at high pressure being transformed into a larger current at lower pressure. The reason of this is the impossibility of getting more watts out of the secondary than are put into the primary: and remembering that the watts in a circuit are made up of the two factors, volts and amperes; it is clear that, if say, the volts are increased, the amperes must diminish, and *vice versâ*. As a matter of fact, the power given out by the secondary circuit is always slightly less than that put into the primary circuit, because a certain amount is absorbed in the process of transformation, chiefly due to the heating-up of the coils, to the setting up of eddy currents, and to hysteresis—as evidenced by the heating of the iron core.

The frequency of the secondary current, however, is the same as that of the primary current.

Transformers are represented diagrammatically as in Figs. 310 and 311, *P* being the primary and *S* the secondary in each case. The first represents a step-up and the second a step-down transformer, the difference in the number of turns in *P* and *S* indicating this.

Dr. S. P. Thompson has pointed out that the static transformer may be regarded as a separately-excited alternating-current dynamo in which there are no moving parts; the necessary fluctuations of the magnetic field being brought about by the use of an alternating exciting current. Regarded in this light, the primary represents the field winding, and the secondary the armature winding.

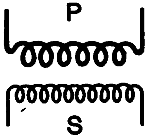

FIG. 310.—Step-up Transformer.

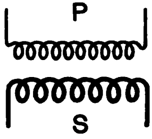

FIG. 311.—Step-down Transformer.

190. EFFICIENCY AND ACTION OF STATIC TRANSFORMERS.—In a well-built transformer, for every 100 watts passed through the primary, from about 85 to 97 will be given out by the secondary; or in other words, the efficiency of a transformer varies from about 85 to 97%. The efficiency of any given transformer is not a constant quantity, however, it being greater at full than at light load, *i. e.* greatest when it is doing its maximum of work.

If all the losses referred to in the previous paragraph were proportional to the load, the efficiency would be a constant quantity; but it happens that the *hysteretic loss* (or loss due to hysteresis) is the same at all loads, for

which reason the efficiency varies. The hysteretic loss increases if the iron core be allowed repeatedly to heat up past a certain degree, this increase being said to be due to the *ageing* of the iron. Ageing may be avoided by keeping the limit of rise of temperature below, say, 140° Fahr.

The efficiency also depends upon other considerations, such as the form of the curve and the frequency of the exciting current, and the inductance or non-inductance of the load (§§ 42, 60).

The connection between the static transformer and the choking coil (§ 50) is a very close one. In fact the transformer might be described as a choking coil with the addition of the secondary winding. Now when the secondary circuit is open, the apparatus acts exactly like such a coil; and the inductance in the primary is very great, so that there is little absorption of energy. When the secondary circuit is closed, and as its resistance is diminished, *i.e.* as more and more load is put on and the current drawn from the transformer increases, the inductance decreases, and more and more of the energy of the primary circuit is absorbed.

This self-regulating effect may be explained as follows. When the secondary circuit is open, the magnetization of the iron core is due to the primary coil alone; and this alternating magnetization is such as to set up an alternating counter E.M.F. in the primary, just as with a choking coil. As the current drawn from the secondary is increased, the magnetization due thereto, which is in opposition to that of the primary coil, causes the inductance of the latter to decrease, so that the current passing through it is also increased. In short, the power

absorbed by the primary circuit of a transformer varies with that taken from the secondary circuit.

The current that may be drawn from the secondary circuit is limited by the size of the conductor, and if too much be taken, the transformer will overheat. If the secondary of a transformer were short-circuited, the heat generated therein might become so great as to destroy the insulation. To prevent this, both primary and secondary circuits should be provided with fuses. Beyond a certain limit, which is represented by the full capacity of the transformer, the terminal pressure at the ends of the secondary circuit will drop considerably as the current drawn therefrom is increased.

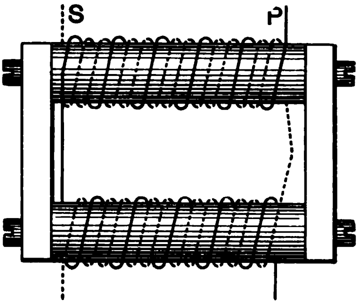

FIG. 312.—Simple Closed-circuit Transformer.

*191. CONSTRUCTION OF TRANSFORMERS. — Practically all static transformers now-a-days have a closed magnetic circuit, that is to say, the circuit is formed wholly of iron, as shown diagrammatically in Fig. 312. The ordinary induction coil, which is represented by Fig. 309, may be termed an open-circuit transformer.

The first transformer, constructed by Faraday, was of the closed-circuit type, and consisted of a solid iron ring *R* (Fig. 313) on separate portions of which the primary and secondary coils *P* and *S* were wound. With this he made the discovery of electro-magnetic induction. Experience has pointed out two grave drawbacks in this form: firstly,

the inevitable leakage of the magnetism, due to the windings of the coils being on separate parts of the ring, so that all the magnetic lines set up by the primary do not pass through the secondary; and secondly, the great waste of energy due to hysteresis in the solid iron (Chap. *VI.* and § 189).

It is essential that the iron parts of transformers should be built up of very thin sheet stampings of pure iron, and that the primary and secondary windings should either be placed one above the other, or close together side by side, the magnetic circuit being kept as short as possible. The core plates are usually about 20 mils (one-fiftieth of an inch) in thickness; and are separately varnished before being piled together, so that they are electrically insulated one from another. This lamination of the iron must be such that the iron is continuous in the path of the lines of force, but discontinuous in a direction at right angles to this, that is in the direction in which eddy currents would tend to be set up.

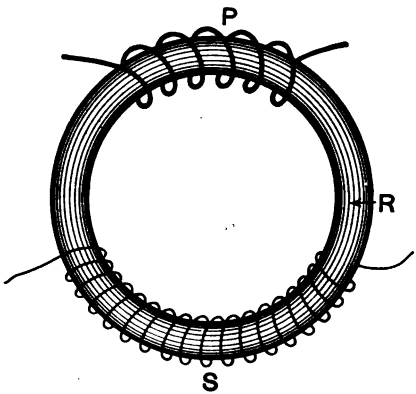

FIG. 313.—Diagram of Faraday's Transformer.

*192. TRANSFORMER SECTIONS.—The following figures show different forms of iron core, and the ways in which the primary and secondary coils may be mounted thereon.

In Fig. 314, the core-plate $C P$ is of rectangular shape, with two holes punched through. One side is cut through at c, so that the middle piece m may be bent up like a flap to facilitate the insertion of the coils P and S; it being bent back flat again when the coils are in position. A perspective view of this type is given in Fig. 315, where $C P$ are the core-plates, and P and S the primary and secondary coils, these being separately wound and bound up with insulation before being put in the "shell." Sometimes the core-plates have one long oblong hole punched through them, as in Fig. 316; the piece p punched out, when placed crosswise, serving to fill the gap in the centre of the coils, as indicated by the dotted line.

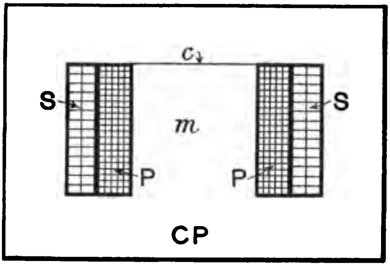

FIG. 314.—Transformer Section.

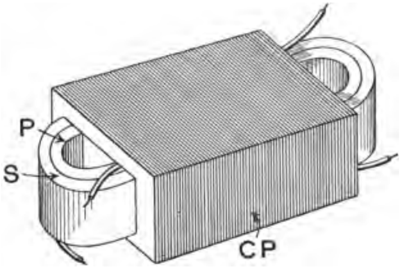

FIG. 315.—Shell Transformer.

Very often the primary and secondary coils of the above and other types of transformer are wound in sections. For instance, the primary may be wound in two separate coils, and these mounted with the secondary sandwiched between them,

the two halves of the primary being then joined in series or in parallel as desired. This is illustrated diagrammatically in Fig. 317, where P, P are the two halves of the primary, and S the secondary winding.

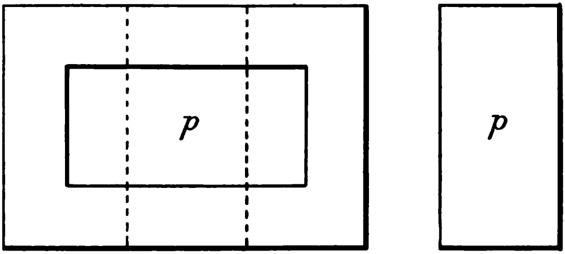

FIG. 316.—Transformer Core-plate.

In Figs. 314 and 317 the section of the "winding" is indicated by a sort of lattice-work. This is the usual way of showing a section of winding in a diagram, it being much more convenient than drawing a number of small circles to represent the wires.

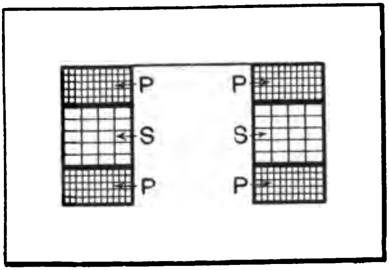

FIG. 317.—Transformer Section.

193. CORE AND SHELL TRANSFORMERS.—A *core transformer*, such as that depicted in Fig. 312, has its core enclosed by the windings. The result is a long magnetic circuit, and a relatively large weight of copper is needed in the windings; but it is a type that is easily wound, and it possesses a

good cooling surface. High insulation is also more easily obtained.

A *shell transformer*, such as that shown in Fig. 315, has its windings nearly wholly surrounded by the core, and its copper and magnetic circuits are about equal in length. Its advantage over the core type is that it possesses a shorter magnetic circuit, and takes a smaller magnetising current, with a less weight of copper. The coils, however, are not readily accessible, and are less able to get rid of their heat than in the core type.

FIG. 318.—Transformer complete (Johnson and Phillips).

It will be seen that the advantages and disadvantages of the one type are about equal, though opposite, to those of the other. That this is the case is evident from the fact that both types are used commercially. Thus the transformers shown in Figs. 318 and 321 are of the core variety, while those in Figs. 323 and 327 belong to the shell class.

The question of cooling has been referred to above. It is necessary that air should have access to the windings in order that the heat generated therein may be carried off. To this end, in transformers of the shell type, special provision has to be made for the ventilation of the windings.

As every type of static transformer consists of primary and secondary windings interlinked in some way by a laminated iron core or frame, there is naturally a strong family likeness between the different makes. It has therefore been thought sufficient to illustrate and describe four actual forms only, as in the next four paragraphs.

194. JOHNSON AND PHILLIPS TRANSFORMER.—This is

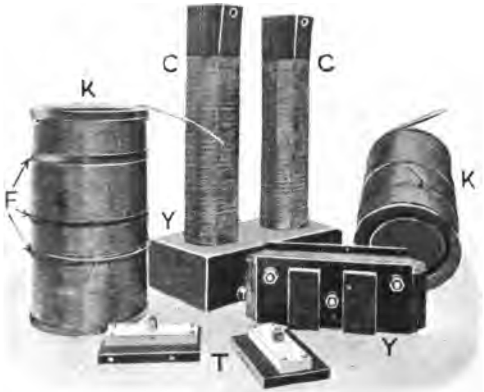

FIG. 319.—Transformer in parts (Johnson and Phillips).

shown complete and in parts in Figs. 318 and 319 respectively, from which it will be evident that it belongs to the core type. The iron circuit consists of two laminated cores, *C, C,* and laminated yoke-pieces, *Y, Y.* These are built up of varnished soft iron plates; those of the cores varying in width, so that the latter, when built up, have an octagonal section. Where the cores and yokes join together the plates are unvarnished and interleave, so as to form good magnetic connection. Before the coils *K, K*

are put on, the cores are taped and varnished, and their octagonal section provides for efficient ventilation when *K*, *K* are in position, the micanite and paper coil-bobbins being circular. There are two of these bobbins on each leg, fitting one inside the other; the secondary winding being on the inner, and the primary on the outer bobbin. Each winding is divided into sections separated by insulating flanges *F*, *F*, *F* on the bobbins. *T* shows one pair of terminal blocks, which are fixed on the yoke. Each brass terminal is mounted on a porcelain base, and the latter on a wooden block.

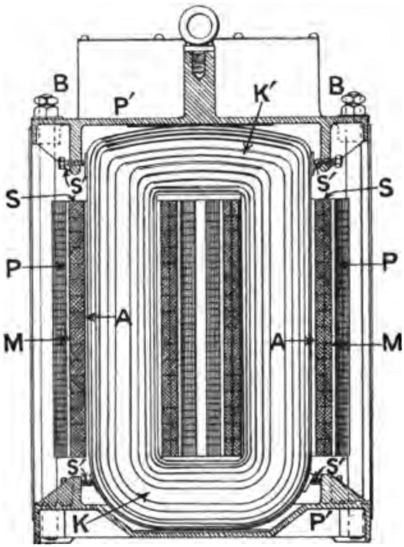

FIG. 320.—Ferranti Transformer (section).

In the complete transformer shown in Fig. 318, the two primary terminals are mounted on a single porcelain slab placed on the top of the core; while on a similar slab at the side are fixed the three secondary terminals, this particular transformer being designed for 3-wire work (§ 197). These transformers are usually mounted in iron cases, something similar to that shown in Fig. 322.

195. THE FERRANTI TRANSFORMER.—The iron circuit of this transformer, which is of the core type, is a particularly good one, there being only one set of joints

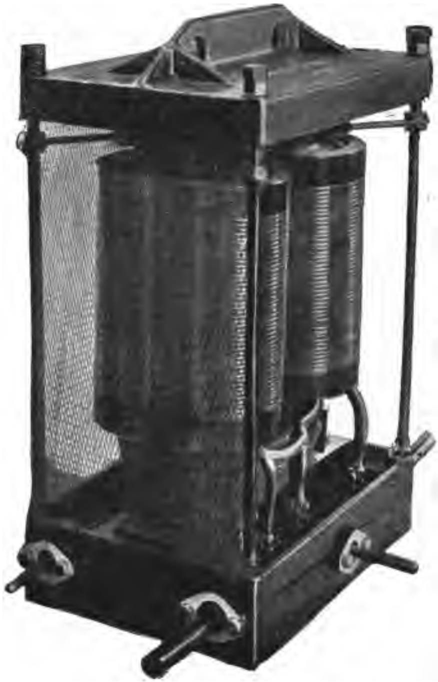

FIG. 321.—Ferranti Transformer with Wire Shield Case.

therein. This will be understood from Fig. 320, showing a section of the transformer. Here it will be seen that the core K, K' consists of a number of plates bent up into a **U**-shape, and then, after the windings have been put

on, bent over and overlapped at the top as at K'. The core is compressed and kept in shape by top and bottom cast-iron plates P', P', the bolts B, B, and set screws S', S', S', S'. The primary and secondary windings are in two sections. The secondary S, S is next to the core, with air spaces

FIG. 322.—Ferranti Transformer in Iron Case.

A, A between, and over it is slipped the primary P, P, the two being separated by thick mica insulation M, M. Mica strip is interposed between the layers of the primary winding, and there is also a layer of mica between the secondary and the air spaces next to the core.

Fig. 321 shows a complete transformer in a wire-shielded

case, the wire netting on two sides being removed. This particular transformer is for three-wire work (§ 197), the cables leading from the two outer terminals and the middle terminal of the secondary winding being shown to the right of the figure. One of the primary leads may be seen on the left. Another way in which the transformer is arranged is as shown in Fig. 322. Here, on the right, the transformer is seen lifted out of its iron case and supported on the top of the same; while on the left it is lowered into the case and the whole closed up. In this construction the terminals, together with the necessary fuses, are in a separate chamber on the top.

FIG. 323.—Berry Transformer (British Elec. Trans. Mfg. Co.).

196. THE BERRY TRANSFORMER.—This apparatus differs very much in form from those transformers already described. It consists of a number of inner and outer vertical and radial laminated iron blocks built up of the usual thin sheet iron, with the coils between. The magnetic circuit is completed at the top and bottom by other laminated blocks placed horizontally; and the whole is held together between top and bottom cast-iron frame-plates by a bolt passing right down the centre. Fig. 323 gives a general view, *W* being the winding, and *B, B, B*, etc., the outer laminated blocks.

The construction will be better understood from Fig. 324, where we may suppose that the top cap and laminated cross-pieces have been removed. Here *I, I, I* and *O, O, O* are respectively the inner and outer radial vertical blocks, *P* the primary, and *S, S* the secondary; the latter being in two sections with the primary sandwiched between, as an extra precaution against shock. It will be evident that this form of transformer possesses excellent ventilation; and this is still further enhanced by opening out the winding at intervals to leave ventilating apertures, as at *A, A, A*. Fig. 324 shows only 6 sets of radial blocks, but the usual plan now is to provide 24 or 36, according to the size of the transformer. That in Fig. 323 has about 20 sets.

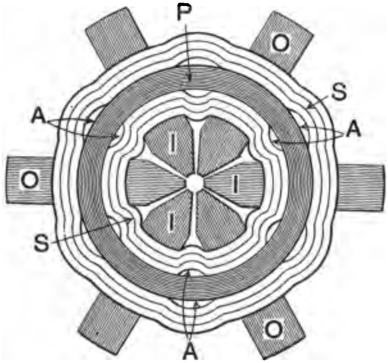

FIG. 324.—Berry Transformer (section).

197. SPECIAL TRANSFORMERS.—By means of a 3-*wire transformer* a three-wire distribution network may be fed from a 2-wire circuit. The only difference between this and an ordinary transformer is that an extra connection is made to the middle of the secondary winding, this being for the third wire. A transformer of this type was illustrated in Fig. 321. Diagrams of such transformers, and of the way they are joined up in circuit, will be found in §§ 232 and 234. There also are given descriptions of other special transformer arrangements.

The term *booster* is generally applied to certain forms of rotary transformer, as explained in § 204. There is, however, a form of static transformer which is sometimes referred to as a *static booster*, though it would possibly be less ambiguous to call it a regulating transformer. It is specially designed for adjusting the pressure on feeders (§ 221). Thus in Fig. 325, *B* are the station bus-bars, *R* the regulable transformer, *F* the 2-wire feeders, and *T* a distant transformer feeding into the low-pressure 3-wire distributing network *N*. The two ends of the primary, and one end of the secondary of *R*, are connected to the bus

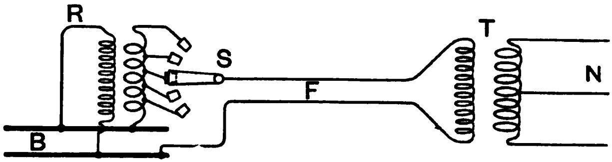

Fig. 325.—Static Booster.

bars as shown. The other end of the secondary, as well as a number of intermediate points, are joined up to a multiple-way switch *S*, to which one of the feeder conductors is attached, the other feeder main being connected to the opposite bus-bar. As will be evident from the figure, by manipulating *S* extra volts may be added to the bus-bar pressure at will, and the drop along *F* compensated for. *R* is a step-transformer, the total secondary P.D. being comparatively small.

The above device possesses rather serious drawbacks, in that the switch *S* has to carry the main current, and that the supply would be stopped if the switch got out of order.

Kapp improved on the arrangement by putting the switch in the primary circuit, as illustrated in Fig. 326. Here *B* are the bus bars, *F* the feeder cables, and *R* the regulable or booster transformer. The contact studs of the switch *S* are joined up to different points in the primary, so that the booster volts induced in the secondary, which are additional to those derived from the bus bars, are adjusted as required.

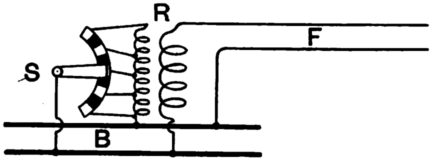

FIG. 326.—Static Booster.

The multiple-way switch is a distinct disadvantage in both the above arrangements, owing to spark-wear, etc. In a form of regulable transformer manufactured by Messrs. Cowans, no switch is necessary. The whole of the primary and part of the secondary winding are mounted on a rotatable core and shaft something like the shuttle

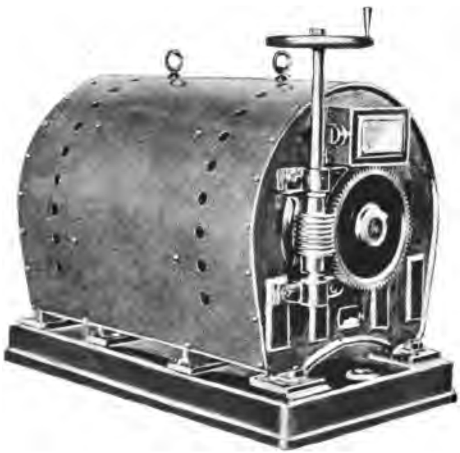
FIG. 327.—Cowan Regulable Transformer.

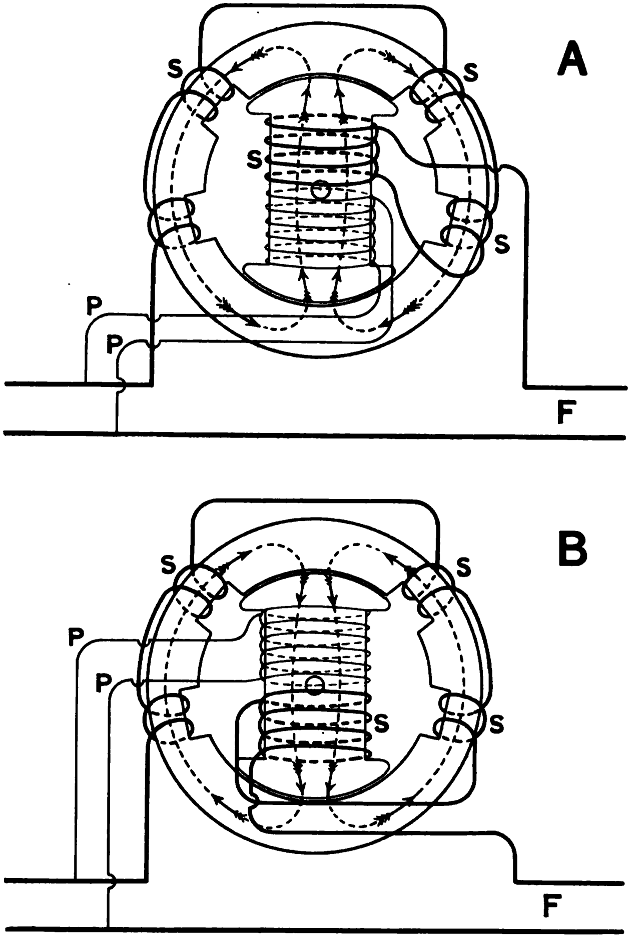

FIG. 328.—Diagrams of Cowan's Regulable Transformer.

N N

armature of a small bipolar dynamo, and the position of this core is adjusted by a hand-wheel and worm-gear. By such means the P.D. induced may be varied from zero upwards.

The external appearance of the apparatus will be gathered from Fig. 327, where the hand-wheel and worm-gear which rotate the shaft are clearly shown. Fig. 328 (*A* and *B*) gives two sectional diagrams of the transformer. With the core in the position shown at *A*, the maximum effect is obtained, the flux due to the primary winding *P*, *P*, passing through the rotatable and fixed portions of the secondary *S*, *S*, *S*, *S* in the same sense, as indicated by the dotted lines and arrows. In the position shown at *B*, where the core has been turned through 180°, no volts are induced in the secondary, for though the primary flux cuts the rotatable portion of the secondary in the same sense as before, it cuts the fixed portion in the opposite sense; and as these two portions have equal effects, no P.D. is set up. The volts induced by the apparatus thus vary according to the position of the rotatable core. Contact between the fixed and rotatable portions is effected by means of slip rings and brushes. The connections shown in the figures are as for boosting purposes, volts being added to the feeder circuit *F* as required. This transformer is also used for testing work.

The ordinary static transformer is a *constant potential* one, for the P.D. at its secondary terminals is kept uniform through normal variations of load. For some purposes, such as for series arc or glow lamp lighting, it is necessary for the transformer to maintain a constant current round the circuit. Such a *constant-current transformer* may be evolved by introducing a choking coil into

the primary circuit of an ordinary transformer so as to increase its inductance. Better regulation, however, is obtained by using transformers in which the distance between the primary and secondary coils is automatically increased or diminished, so that the E.M.F. induced is

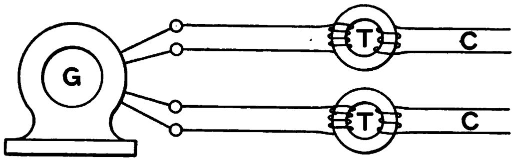

FIG. 329.—Single-phase Transformers on Two-phase Circuit.

decreased or increased to fit the conditions of the outside circuit. Such a transformer is used in the Ferranti rectifier and is described in § 207.

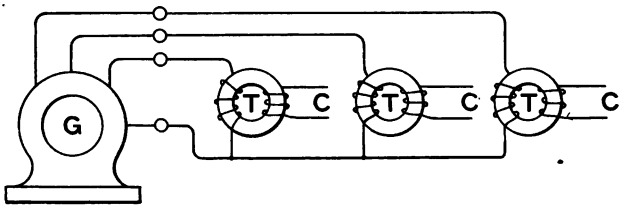

FIG. 330.—Single-phase Transformers on Three-phase Circuit.

198. ORDINARY TRANSFORMERS ON POLYPHASE SYSTEMS.—Both 2- and 3-phase systems require either three or four conductors for the transmission of their energy, the number depending on the circuit arrangements adopted. Fig. 329 represents a diphase generator, the two currents of which are kept quite distinct, and are stepped down by ordinary single-phase transformers *T*, *T*

to feed separate circuits at *C, C*. Similarly Fig. 330 represents a 3-phase generator feeding separate circuits, *C, C, C* through single-phase transformers *T, T, T*. These, however, are simple cases only.

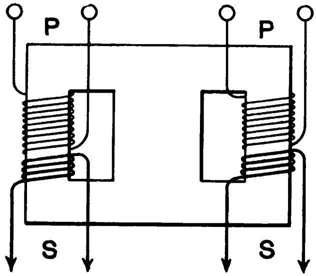

FIG. 331.—Diagram of Two-phase Transformer.

199. TWO- AND THREE-PHASE TRANSFORMERS.—Instead of employing separate transformers, it is more economical, as far as iron is concerned, to combine the windings on a common core, and Figs. 331 and 332 show diagrammatically the arrangement of 2- and 3-phase transformers respectively. The core section in the former is of that shape so common in single-phase transformers (Fig. 314); while the latter consists of three cylindrical cores united by a common yoke at each end.

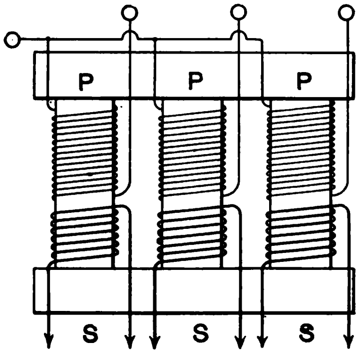

FIG. 332.—Diagram of Three-phase Transformer.

200. PHASE TRANSFORMERS.—A *phase transformer* is one for altering the *character* of an alternating supply. By means of such, monophase may be converted into either 2- or 3-phase, or *vice versâ;* or 2-phase into 3-phase, or 3-phase into 2-phase currents.

There are various methods of attaining these ends, and the transformers are either static or rotary, or a combination of both. The consideration of these, however, does not come within the scope of this book.

The student desiring full information concerning poly phase working cannot do better than consult S. P. Thompson's admirable treatise, *Polyphase Electric Currents.*

201. THEORY AND CALCULATIONS.—Referring to Fig. 312 representing a simple transformer, when current is sent through the primary, E.M.F. is induced not only in the secondary but also in the primary winding, the latter being a back E.M.F.

If Ep be the back E.M.F. induced in the primary circuit, n the frequency, Tp the number of turns in the primary, and F the maximum total flux passing through the core :—

$$\text{Ep (in virtual volts)} = \frac{4{\cdot}45 \text{ n Tp } \mathsf{F}}{10^8} \qquad \text{(I.)}$$

$$\text{Similarly Es} = \frac{4{\cdot}45 \text{ n Ts } \mathsf{F}}{10^8} \qquad \text{(II.)}$$

where Es and Ts are respectively the virtual pressure induced and the number of turns in the secondary winding. 4·45 is the value of the coefficient for a sine wave of E.M.F., but this is slightly different for waves of other forms (§ 42).

Any one of the quantities given above can be found if the others be known, one example of the use of the formulæ being as follows.

Example.—The net sectional area of the core of a transformer is 46·5 square inches, and the alternating flux due to the primary is equivalent to 3000 lines per square inch. The frequency being

50 ~ per sec., how many turns must the secondary winding have in order that it may generate an E.M.F. of 255 volts on open circuit?

Taking formula II., above :—

$\mathbf{F} = 46{\cdot}5 \times 3000$, $n = 50$, $Es = 255$, and Ts is required.

Transposing formula II :—

$$Ts = \frac{Es \times 10^8}{4{\cdot}45\ n\ \mathbf{F}}$$

$$i.e. \quad Ts = \frac{255 \times 10^8}{4{\cdot}45 \times 50 \times 139500} = 822 \text{ turns.}$$

When a transformer is on open circuit, the ratio between the E.M.Fs. in the two windings is exactly proportional to the ratio between the numbers of turns, or :—

$$Ep : Es :: Tp : Ts.$$

$$i.e. \quad \frac{Es}{Ep} = \frac{Ts}{Tp} = k. \qquad \text{(III.)}$$

k being termed the *ratio of transformation.* Thus if the secondary have one-tenth the number of turns that the primary has, its E.M.F. will be one-tenth that of the primary, and so on.

In practice it is usual to speak of the ratio of transformation as 10, 20, or 30 to 1 as the case may be, instead of, if a step-down transformer, $\frac{1}{10}$th, $\frac{1}{20}$th, or $\frac{1}{30}$th to 1. Thus a 20 to 1 step-down transformer is one in which the secondary volts are $\frac{1}{20}$th of the primary volts. A 20 to 1 step-up transformer is one in which the secondary pressure is 20 times as great as that in the primary.

Let Vp be the P.D. at the terminals of the primary winding, and Vs that at the terminals of the secondary winding; and Rp and Rs, and Cp and Cs their respective resistances and currents. Then the loss of volts in the primary will be Rp Cp, and that in the secondary Rs Cs.

And :—

$$Vp = Ep + Rp\,Cp \qquad \text{(IV.)}$$
$$\text{and } Vs = Es - Rs\,Cs \qquad \text{(V.)}$$

Vp, it may be explained, are the volts actually applied at or impressed on the terminals of the primary circuit; and a portion (Rp Cp) of these is lost in forcing the current through the resistance of the winding. The remainder (Ep) is that portion required to overcome the back E.M.F. when the transformer is on open circuit; but when the secondary circuit is closed, more or less of Ep is employed as *inducing E.M.F.* In other words, when a transformer is on open circuit, *i.e.* when its secondary is on open circuit, the E.M.F. (equal to Ep) induced in the primary acts wholly as back E.M.F., the apparatus then being simply a choking coil. Directly current is drawn from the secondary, part of the primary E.M.F. is employed in inducing this current, or rather in keeping up the pressure in the secondary: the back E.M.F. is consequently reduced, and a greater current allowed to flow through the primary. As more and more current is drawn from the secondary, so less and less becomes the proportion of Ep overcoming the back E.M.F., and the greater the proportion acting as inducing E.M.F. The greater also becomes the current flowing through the primary. This self-regulating effect of a transformer was alluded to in § 190, and is somewhat similar to that of a motor. The E.M.F. (Es) induced in the secondary is greater than the P.D. at the secondary terminals (Vs), by an amount equivalent to the volts lost therein (Rs Cs).

If we disregard the small losses due to magnetic leakage, hysteresis, and eddy currents; the power absorbed

in the primary, apart from that wasted by ohmic resistance, may be assumed to be equal to that generated in the secondary. In other words, we may say that the inductive work done in the secondary is practically equal to the magnetizing work done in the primary.

That is:— $$\text{Ep Cp} = \text{Es Cs},$$

or:— $$\frac{\text{Es}}{\text{Ep}} = \frac{\text{Cp}}{\text{Cs}};$$

but by III.:— $$\text{k} = \frac{\text{Es}}{\text{Ep}},$$

so that:— $$\text{k} = \frac{\text{Cp}}{\text{Cs}}$$

and:— $$\text{Cp} = \text{k Cs}. \qquad \text{(VI.)}$$

Now by IV. and VI. $$\begin{aligned} \text{Ep} &= \text{Vp} - \text{Rp Cp} & \text{(VII.)} \\ &= \text{Vp} - \text{k Rp Cs} & \text{(VIII.)} \end{aligned}$$

By III.:— $$\text{Es} = \text{k Ep} \qquad \text{(IX.)}$$

Substituting the latter for the former in V, we get:—

$$\text{Vs} = \text{k Ep} - \text{Rs Cs}. \qquad \text{(X.)}$$

This formula, amongst other things, enables the secondary terminal pressure to be found, when the current to be drawn therefrom, and the E.M.F. induced in the primary are known.

The following is one of various practical problems that may be solved by the above formulæ.

Example.—A well-designed transformer, having a primary coil of 750 turns with a resistance of $4{\cdot}5\omega$, is connected with a 2000 volt circuit, and is taking 8 amperes therefrom. The secondary winding has 100 turns, and its resistance is $\cdot01\omega$. Neglecting the small leakage, eddy-current, and hysteretic losses, calculate the P.D. at the secondary terminals when 300 amperes are being drawn from it.

Using the above formulæ, we first find the ratio of transformation, which is :—

By III. :— $k = \frac{100}{750} = \cdot 133$

By VII. :— $Ep = 2000 - (4{\cdot}5 \times 8)$
$= 1964$ volts.

And by IX. :— $Es = 1964 \times \cdot 133 = 261$ volts.

Then by V. :— $Vs = 261 - (\cdot 01 \times 300)$
$= 258.$

Thus the P.D. at the secondary terminals will be 258 volts.

Vs may also be got by means of formula X.

*202. ROTARY TRANSFORMERS.—As already explained (§ 187), a *rotary transformer* or *motor transformer* is a combination of a motor and a dynamo or alternator, and hence is often termed a *motor-generator*. By means of such a machine, electrical energy is changed either in pressure or character, or in both. In one case the supply to be transformed is led into a motor, and this being coupled to a generator, the latter gives out currents of the pressure and character desired. Such a combination with motor and generator armatures quite distinct is more rightly termed a motor-generator than a rotary or motor transformer; the latter term being more applicable to those machines in which the motor and generating parts are mounted on a common core. In the latter case, the windings, though mounted on the same core, are usually quite distinct; but in some special machines, one set of windings acts for both sides of the system (§§ 79A and 205).

The *direct-current transformer* (frequently also termed a *motor-dynamo*)[1] is one for either lowering or raising

[1] The term *dynamotor* is sometimes used in the same sense, but the name is obviously a loose one, inasmuch as a direct-current transformer is always a motor *firstly*, and a generator *secondly*, so to speak.

the pressure of a direct current, but usually the former. Sometimes the primary and secondary armature windings (as we may term those of the motor and dynamo respectively) are wound on separate cores revolving in separate fields; while sometimes they are mounted on the same core, though kept separate, and revolve in a common field. Each winding of course has its separate commutator. The coils of the field magnet or magnets

FIG. 333.—Motor-Dynamo (Keighley Elec. Eng. Co.).

are sometimes connected in shunt to the secondary armature, and sometimes to a separate source of current.

*203. TYPES OF MOTOR-GENERATOR.—Fig. 333 represents an ordinary motor-dynamo, formed by coupling the shafts of two direct-current machines together, and using one as a motor to drive the other as a dynamo. The two field windings are connected up in parallel to the secondary or dynamo terminals, the residual magnetism in the motor magnet being sufficient to start the machine.

Fig. 334.—Motor-Dynamo (Electric Construction Co.).

The uses to which such a combination may be put are very numerous. In distribution, for instance, these machines may be employed to transform down from high to low pressure, as, for instance, from 2000 or 1000 volts down to, say, 250; the motor being connected with the high-pressure feeders, and the dynamo with the low-pressure distribution network. Then again, motor-dynamos connected to the supply mains may be employed to reduce the pressure, as for electro-plating, etc.; or to raise it for experimental purposes.

Fig. 334 shows a motor-dynamo with the two armature windings on a single core, and rotating in a single magnetic field. The latter has two windings, shunt and series, the former being connected to the secondary terminals. The series winding is in series with the primary circuit, and its function is to increase the initial field and so enable the motor to start up quickly. As soon as the machine is rotating at its full speed, the series winding is cut out by an automatic switch, which is operated by the stray field from the magnet poles, and is mounted on the top thereof. Should the machine afterwards become demagnetized from any cause, the switch throws the series winding in circuit again. This series starting winding is not necessary in every case, as the residual field of the magnet is usually sufficient to start the motor. In this particular make of machine, the primary and secondary windings are placed one above the other on the armature core, with an earthed metallic shield between them to prevent the high pressure leaking into the low-pressure circuit. As may be judged by the numbers and sizes of the brushes on the two commutators, these indicating the

respective current densities, the high-pressure commutator is that at the left-hand end of the machine.

The motor-generator combination shown in Fig. 335 consists of a three-phase machine coupled to a direct-current

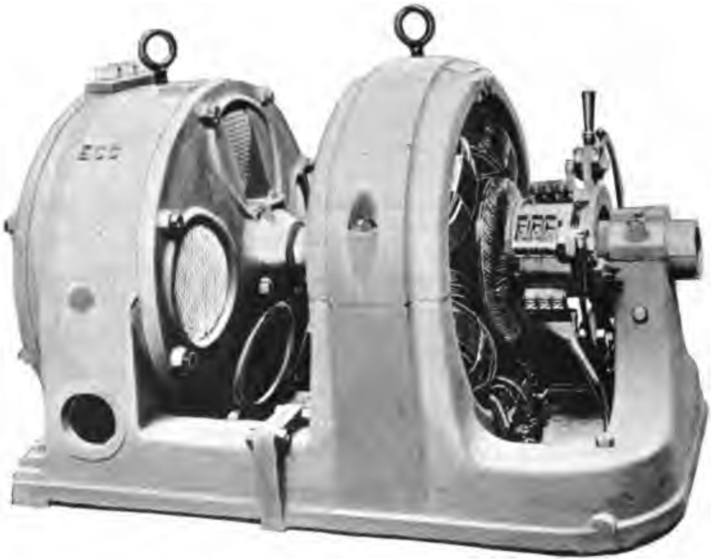

FIG. 335.—Motor-Generator (Electric Construction Co.).

one, the latter being on the right-hand side. Such may be used to transform 3-phase to direct-current or the reverse, this depending on which machine is used as the motor.

On 3-wire systems, motor-dynamos with equal windings may be used to keep balance between the two sides of the system. Such are termed *balancers* or *equalizers*, and their action is fully explained in §§ 225 and 226.

204. BOOSTERS.—The term *booster* is generally applied to certain forms of rotary transformer which are used for various special purposes, in which only a slight transforming-up or "boosting-up" of the driving voltage is required. Thus there are *battery-charging boosters, feeder boosters, balancer boosters,* etc. A *reversible booster* either adds to or subtracts from the line voltage (§§ 227, 228).

When secondary batteries are used in central or sub-stations to supply at times of light load, the ordinary bus-bar or feeder pressure, as the case may be, is not

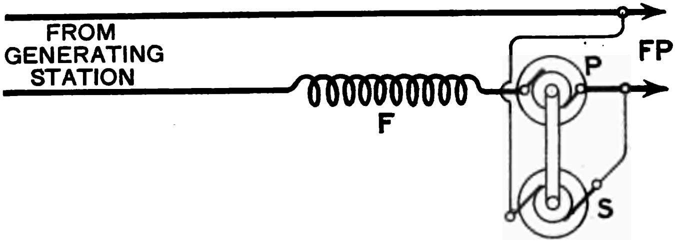

FIG. 336.—Rotary Feeder-Booster.

sufficiently great to charge them. To accomplish this a step-up motor-dynamo is employed, the secondary pressure of which is just sufficiently higher than that of the primary to enable it to charge a battery which discharges at the primary voltage. This is a *battery-charging booster*, and its action was fully described in § 181.

A very common use for a booster is to make up for the drop in volts at the end of long feeder. Thus in Fig. 336 *P* and *S* are the primary and secondary windings, and *F* the field coil of what may be termed a *rotary feeder booster*, to distinguish it from the static feeder boosters mentioned

in § 197. *P* and *F* are connected as a series motor in circuit with one of the feeder cables, and *S* delivers its pressure to the cables at the feeding point *F P*, increasing the P.D. at this point where they feed into the distributing network. Here the self-regulating action of the booster will be apparent. The greater the current drawn through the feeder cables, the greater will be the tendency for the pressure to drop; but the machine will counteract this tendency, as its speed will increase with the current.

Fig. 337.—Balancer-Booster (Lancashire Dynamo and Motor Co.).

A *balancer booster* is formed by coupling four machines on one shaft, as in Fig. 337. A description of the use of such is given in § 237. A *reversible booster* is one which boosts in either direction as required, the reversal being automatic. Such machines, though only recently introduced, have been found to possess so many excellent

qualities that their use is rapidly extending. They are fully dealt with in §§ 227 and 228.

There are various other booster arrangements which cannot be considered here.

205. CURRENT-CHARACTER TRANSFORMERS.—It will be clear that, by coupling the right kind of motor to the right kind of generator, the character as well as the pressure of the current may be transformed just as desired. Illustrations of such machines were given in Figs. 229 and 335; and some idea of the possible combinations will be obtained from the following table:—

	MOTOR.	GENERATOR.
(*a*)	Polyphase.	Single-phase.
(*b*)	Polyphase.	Direct.
(*c*)	Single-phase.	Direct.
(*d*)	Direct.	Polyphase.
(*e*)	Direct.	Single-phase.
(*f*)	Direct.	Direct.

Type *f*, by the way, is not a character transformer, but a pressure transformer simply. This class of machine was the first to come into extensive use, but type *b* has now become the most important combination, as it is employed in connection with many of the large new generating and distributing systems (§ 239).

To secure the advantages of polyphase motors in factories, when the supply is a direct-current one, a transformer of type (*d*) may be used (Fig. 335). In the case of the two types (*b*) and (*d*), instead of coupling a self-contained motor to a generator, the two machines may be

combined, with a great gain in efficiency. The double-current generators described in §§ 79 and 79A are, as a matter of fact, examples of this combined construction; for they will act as rotary transformers of these two classes when driven by polyphase or direct currents respectively. Their use is further referred to in §§ 217 and 232.

206. RECTIFIERS.—A rectifier is an appliance for transforming single-phase (and sometimes polyphase) alternating into intermittent direct or *rectified current.*

When the generators in a central station are of the single-phase alternating-current type, the arc lighting circuits are sometimes supplied with rectified current from Ferranti rectifiers, this being the special purpose for which these machines, which are fully described in the next paragraph, were designed.

For very small currents the Batten rectifier (§ 208) will be found useful.

The *Nodon "valve"* (§ 209) may be termed an *electrolytic rectifier.* This is a comparatively new device, but it is stated to be capable of dealing with large outputs.

The *Cooper-Hewitt rectifier* transforms 3-phase into direct current. It is marvellously simple, consisting simply of a vacuum globe fitted with five special electrodes. At the time of writing, the apparatus has hardly emerged from the laboratory stage of existence; and its action, moreover, is not easy to explain in simple language. Consequently, we shall not deal further with it here.

Although, broadly speaking, any form of rectifier might be termed a transformer, it is more correctly described as a commutating machine or appliance; the commutation or rectification of the alternating current being performed

either mechanically, as in the Ferranti and Batten rectifiers, or chemically, as in the Nodon valve.

The Nodon and Cooper-Hewitt apparatus are sometimes termed *static rectifiers*, as there are, practically speaking, no moving parts in them.

207. THE FERRANTI RECTIFIER.—This apparatus is designed for use on alternating-current systems where it is desired to avoid the employment of alternating current for the arc lighting. It may be roughly described as consisting of a motor-driven commutator of special construction, the office of the commutator being to render the

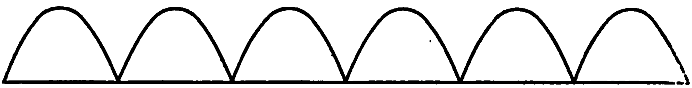

FIG. 338.—Rectified Current.

waves of current unidirectional. The resulting pulsating direct current, which is led round the lamp circuit, and which may be diagrammatically represented as in Fig. 338, is considered to possess certain advantages over the ordinary unfluctuating direct current, as by reason of its intermittent character, the lamps are probably less liable to stick or "hang-up" as it is termed.

Since it was first introduced, the Ferranti rectifier has been improved in construction from time to time, and its latest form is as shown in Fig. 339. In more precise language than that used above, its action may be thus described. It gives out to the arc-lighting circuit a rectified current which is kept constant whatever the

number of lamps in circuit, owing to the rectified E.M.F. varying to suit the requirements of the circuit: and it is fed at constant potential with an alternating

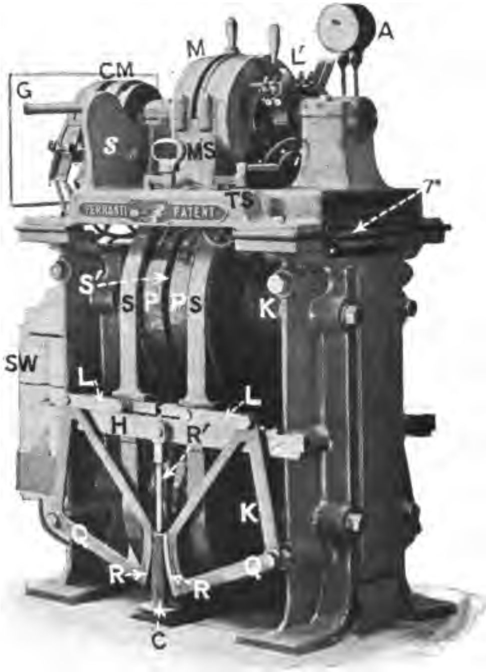

FIG. 339.—Ferranti Rectifier.

current, the strength of which varies in sympathy with the rectified power given out. It consists of three essential parts:—

a. A transformer in which the two coils into which

the secondary winding is split up are movable; their distance from the primary, and therefore the E.M.F. induced in them, varying so as to keep the current in the arc-lighting circuit constant in spite of varying resistance.

b. A synchronous alternating-current motor, *i. e.* one running at a constant speed in synchronism with the frequency of the alternating current supply. And—

c. A specially arranged rectifying commutator driven by the motor.

We will deal first with the transformer. *S, S* are the two movable secondary coils, and *P, P* the two halves of the fixed primary; a separate fixed secondary winding being sandwiched in between at *S'*. The current induced in the latter is used for driving the motor. The gun-metal frames supporting *S, S* run on ball bearings carried by the horizontal bar *H*; and these frames are geared together, through the links *L, L*, by the quadrant pieces *Q, Q*, and racks *R, R*, which engage with a corresponding rack cut on the upper portion of a counterpoise *C*. Except for weights at the bottom, *C* is hollow, and slides up and down the fixed rod *R'*, the lower end of which carries a disk closely fitting the inside of *C*, which is filled up with oil, so that the disk acts as a dash-pot. *C* is longer than appears from the figure, the lower end passing beneath the floor. A similar arrangement of quadrants, counterpoise, etc., is fitted to the other side of the machine. The three fixed and the two moving coils have a common magnetic circuit, which consists of two horizontal laminated cores of circular section in the positions *K, K*, these being united by laminated yoke-pieces let in each side of the cast-iron frame. Fig. 340 shows one of the movable secondary coils in diagram, this

being composed of two inter-connected coils C, C' fixed in a gun-metal frame F, F; B, B being the bearing pieces which run on the balls. K, K are the two fixed horizonta iron cores over which C and C' move. From this it will be evident that each of the so-called coils S, S, P, P, and S' (alluded to in connection with Fig. 339) really consists of two windings, disposed as in Fig. 340, those of P, P and S' being fixed, however.

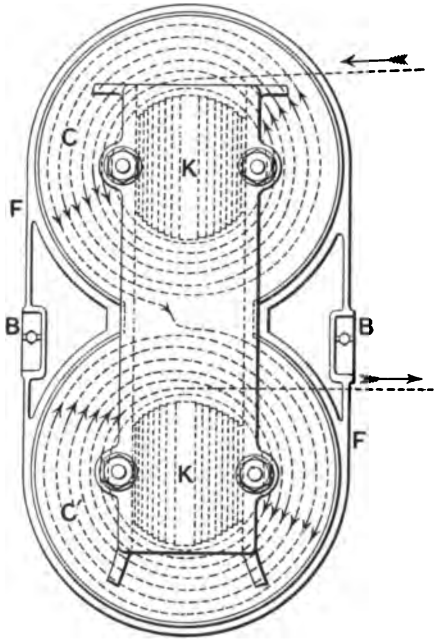

FIG. 340.—Ferranti Rectifier (Section of Cores and Coils).

Returning now to Fig. 339, let us consider the action of the movable coils and their gearing. The counterpoise C tends to pull down the quadrants Q, Q, and so keep the coils S, S close alongside the fixed primaries P, P; but at times, the magnetic repulsion existing between P, P and S, S is great enough to force the coils apart. The counterpoise, or rather the counterpoises (for it must be remembered that there is one on each side), are so adjusted that when the maximum number of arc lamps is in circuit, the

secondaries are close up to the primaries, and the maximum induction takes place between them. If any of the arcs are cut out of circuit, the resistance of the secondary circuit (of which the arc lamps, through the interconnection of the commutator, form a part) is decreased, and the induced current momentarily increases. The repulsion between the coils then rises above the normal, and becomes great enough to overcome the counterpoises. The coils then move outwards until the number of lines of force passing through them is so far reduced as to keep the current at its normal value. So sensitive is this arrangement, that a machine which at one moment may be supplying 40 lamps on a series circuit, will immediately adjust itself to the altered conditions if 10, 20, or more of the lamps be switched off simultaneously. Indeed, the rectified-current circuit will suffer short circuiting with practically no increase in the secondary current, the coils immediately opening out to their utmost extent.[1]

In Fig. 339, *Sw* is a specially constructed quadruple water-break switch, through which the constant alternating current from the secondary coils *S*, *S* passes to the commutator *CM*. The construction of the latter is shown diagrammatically in Fig. 341, where the commutator may be supposed to have been cut across at one point, and then flattened out. The brushes *B*, *B*, to which the ends of the lamp circuit are connected, press on two insulated collector rings $R+$, $R-$, placed a few inches apart, and having

[1] It may be mentioned here that Messrs. Ferranti make a *constant-current transformer* on the above principle, the apparatus resembling that in Fig. 339, except that there is no motor and no rectifying commutator.

projections P, P, P', P' thereon. Between neighbouring pairs of projections are two contact pieces $I\,P$, $I\,P$, which are connected together, but unconnected with P or P'. Between these are sets of insulated metal ridges, R, R, etc., which serve to break up the sparks as the pairs of secondary circuit brushes pass from P to $I\,P$, $I\,P$ to P', and so on. There are two pairs of these brushes, viz. b, b and b', b'; the two sections S, S of the secondary winding being connected to them. While the secondary current is in one direction, as shown by the firm arrows, the two coils are connected together through b, b and $I\ P$; and the current is delivered by b', b' to the collector rings $R+$ and $R-$, on which the arc circuit brushes bear.

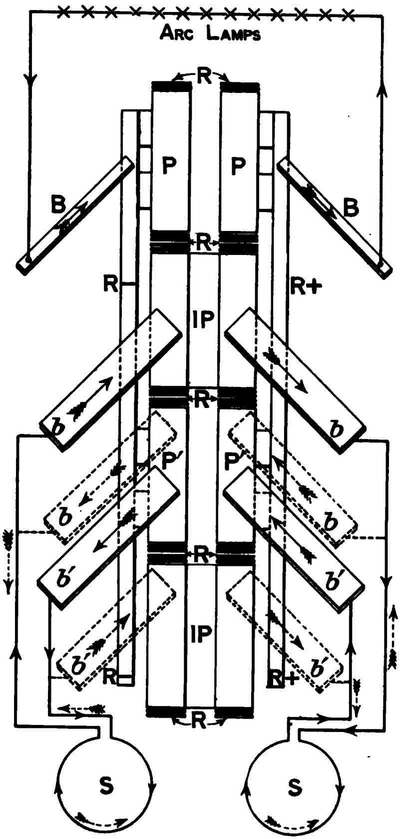

FIG. 341.—Rectifying Commutator.

As the commutator segments are supposed to be travelling upwards, immediately the current in *S*, *S* changes to the direction shown by the dotted arrows, *b*, *b* and *b′*, *b′* will have reached the dotted positions indicated; so that the current, though reversed in *S*, *S*, will still flow in the same

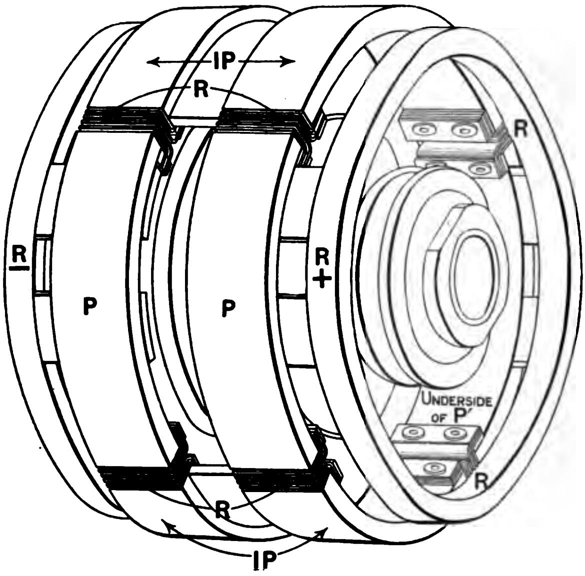

FIG. 342.—Commutator of Ferranti Rectifier.

direction in the arc circuit. Directly after this, *b*, *b* will again be connected together, and *b′*, *b′* joined-up to the arc circuit; and so on. The commutator revolves in synchronism with the alternations of the current in *S*, *S*, and the changes in the connections of the brushes at the ends of *S*, *S* change in step with the alternations of the current.

The actual commutator, removed from its shaft, is shown in Fig. 342; and the parts corresponding with those in Fig. 341 are similarly lettered.

In Fig. 339 some of the commutator-brushes can be seen, and it should be noticed that the commutator, which it would be dangerous to touch, is shielded on one side by the flange *s*, and on the other by a glass plate *G*. *M* is

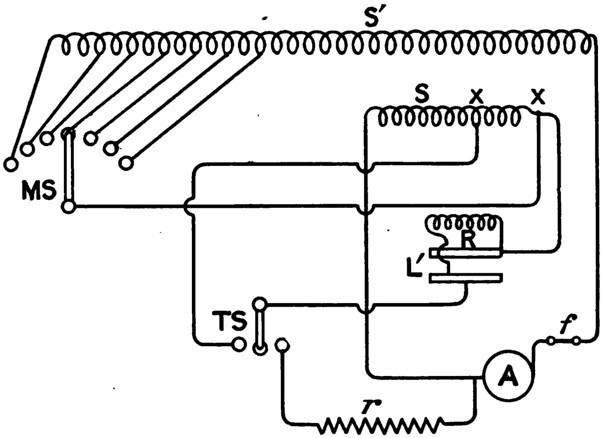

FIG. 343.—Connections of Rectifier Motor.

the motor, *A* an ammeter in circuit therewith, *r* a starting resistance, *MS* a multiple-way regulating switch, and *TS* a two-way switch. The stator of the motor carries an alternating current derived from the fixed secondary coil *S′*, different turns of which are connected up to the studs of *MS*, so that the pressure may be adjusted as necessary. The rotor is fed with rectified current through a simple low-pressure commutator at *L′*. The motor

connections are illustrated in Fig. 343. Here S' is the fixed secondary coil of the transformer, tappings from which are led to the multiple-way switch $M\,S$. S is the stator winding, a few volts being taken off at $x\,x$ for the rotor winding R, which is connected with the commutator L'. $T\,S$ is the two-way switch, which is moved to the right for starting, thereby sending the current through the resistance r; and to the left when speed has been got up, r being thereby cut

FIG. 344.—Batten Rectifier (Gen. Elec. Co.).

out. A is the ammeter, and f a fuse. If the connections be traced out, it will be seen that R is connected in parallel with that portion of S between $x\,x$. On starting, the full voltage on S is applied to R through r, but when synchronous speed is attained, and $T\,S$ is moved to the left, the volts between $x\,x$ are tapped for R, and r is cut out.

208. THE BATTEN RECTIFIER.—This apparatus is illustrated in perspective in Fig. 344 and diagrammatically in Fig. 345. It is useful for small and occasional work where direct current is required but only an alternating supply

is available. For instance, it may be employed for charging small accumulators, exciting spark coils, driving small motors, performing electrolytic work on a limited scale, and so forth.

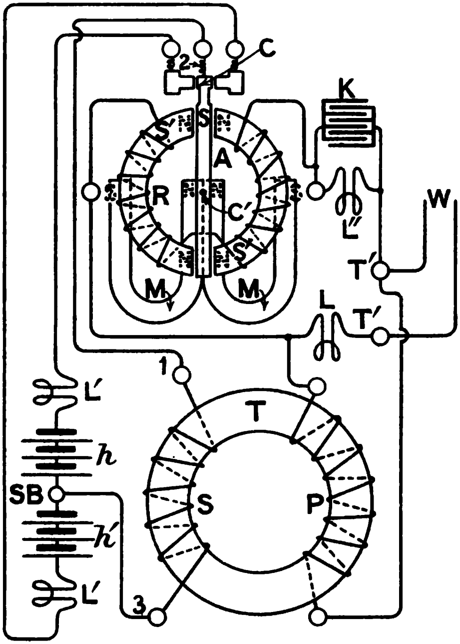

Fig. 345.—Diagram of Batten Rectifier.

The diagram of the instrument should be compared with the figure of the actual apparatus. It consists of a step-down static transformer *T*, by means of which the circuit pressure is reduced to about 50 volts; and a polarized relay *R*, the contact tongue *C* of which moves to

one side or the other in sympathy with the alternations of the current in the primary winding P; the secondary current induced in the winding S being thereby rendered unidirectional in the outer circuit. T', T' are the main terminals, which are connected to the alternating current supply through the wires W. The lamps at the back of Fig. 344 are used as resistances in the primary circuit, the reduction of the voltage already alluded to being effected by this means. These may be inserted say at L in Fig. 345.

In charging accumulators or similar work where a low pressure is wanted, a lamp (or lamps) is also connected in the secondary circuit. Fig. 345 shows this, SB being a secondary battery, and L', L' the lamp resistances in series therewith. The accumulator, be it noted, has one end of the secondary S connected to its middle. Thus the alternating current leaving the transformer by the wire *1*, passes by the flexible connection *2* to the vibrating contact tongue C of the relay; the latter causing the currents in either direction to flow through the two halves h and h' of the battery respectively, whence the current re-enters the secondary of the transformer by the wire *3*.

The soft iron core of the relay is in two halves S'', S'', and the armature A carrying C, vibrates between their polar extremities. M, M are two permanent magnets with their like poles together at the centre C' where A is pivoted. Supposing these poles are north as indicated, the extremities of A will be south. The south ends of M, M being in juxtaposition with the centres of the soft iron cores S'', S'' will render their extremities facing the ends of A of north polarity. The windings on S'', S'' are connected in series with each other, and in shunt with P across the

main terminals T', T'. Then because of the polarization of A and S', S', the former will vibrate rapidly in sympathy with the alternations of the current. K is a condenser shunted by a lamp resistance L'', this being found to improve the working of R.

209. THE NODON "VALVE," OR ELECTROLYTIC RECTIFIER. — This apparatus, the invention of M. Nodon, and peculiarly named by him the *electric valve*, is better termed an *electrolytic rectifier*, the alternating current being rendered unidirectional by the action of electrolysis.

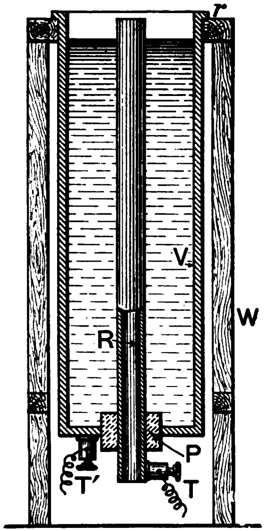

FIG. 346.—Single Cell of Nodon Rectifier.

The apparatus is generally composed of four electrolytic cells of the construction shown in section in Fig. 346. Here V is a containing vessel of iron, open at the top, where an external rim r allows of its suspension in a wooden frame W. Passing through a rubber plug P at the bottom, is a hollow rod R of an alloy of zinc and aluminium, carrying a terminal T at its outer and lower extremity. Another terminal T' is affixed to V.

The electrolyte consists of a saturated solution of ammonium phosphate, the peculiarity of which is, that when the current flows or tends to flow from R to V, a highly resisting film, sufficient to stop the passage of the current, is instantly formed on R. When, however, the pressure is

in the reverse direction, the film immediately dissolves and allows the current to pass. This film is of complicated composition, which we need not consider, the main thing to remember being that such a cell will allow a current to pass through it in one direction only, viz. from the iron to the alloy rod.

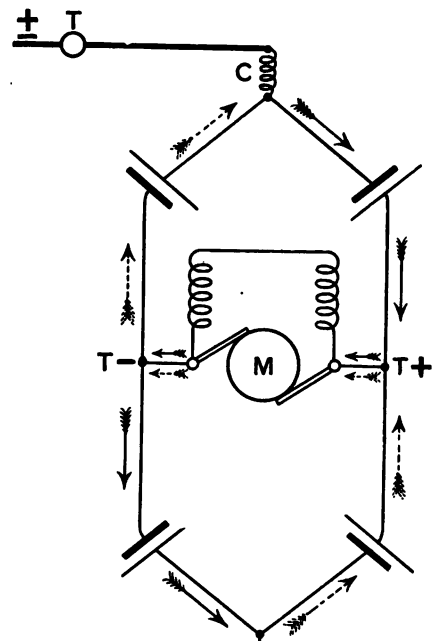

Fig. 347.—Diagram of Nodon Rectifier.

A complete rectifier generally consists of four such cells connected up, as shown in the diagram Fig. 347, with their poles in opposition; the short thick lines representing the iron of the containing vessels, and the long thin ones the alloy rods. *T, T* are the alternating-current supply terminals, *C* a choking coil or a rheostat for adjusting the pressure of the supply, and *T*+ and *T*− the terminals from which the rectified current is taken, a motor *M* being shown connected thereto in this instance.

The effect of so joining up the cells is that when a

current impulse tends to flow from the top to the bottom main terminal, it has to pass through the top right-hand cell, then *viâ* $T+$ and $T-$ and the bottom left-hand cell to the bottom wire; the top left-hand and bottom right-hand cells obstructing the current in this direction. When, however, the current reverses and flows from the bottom to the top terminal, it does so through the bottom right-hand and top left-hand cells *viâ* $T+$ and $T-$. The directions of the downward and upward currents are respectively shown by the firm and dotted arrows; and it should be particularly noticed that both flow from $T+$ to $T-$. When no apparatus is connected between these terminals, there will be no current through the rectifier; but the terminals will be maintained at a $+$ and $-$ potential respectively, ready to give current directly anything is joined across.

Fig. 347A.—Nodon Rectifier.

Fig. 347A shows a complete rectifier, the part protruding at the top consisting of insulating sleeves, which may be slipped more or less over the alloy rods, so as to regulate

the output of the cell. When such sleeves are employed, the choker or rheostat C (Fig. 347) is not necessary.

CHAPTER XVI.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. What are transformers, and what are they for? [Prel. 1895.]

*2. Give sketches showing diagrammatically, and explain the difference between, step-up and step-down transformers.

*3. State concisely the difference between an ordinary induction coil and a step-up transformer, both as regards construction and action.

4. The current from an alternating current dynamo is sent through a coil of wire: another closed coil of wire is brought near it and becomes very hot; what is the reason for this? [Ord. 1890.]

5. Explain clearly why it is that an alternating current in a coil induces an alternating current in a neighbouring coil.

*6. If the primary of a transformer is connected up to an alternating supply of suitable frequency and voltage, only a very small current will pass as long as the secondary circuit is open, but if the primary were connected up to a continuous supply of the same voltage, a very large current would pass, and the winding would be burnt out, whether the secondary were open or closed. How would you explain this? Would any action take place in the secondary winding in the second case? if so, when, and why? [Prel. 1902.]

7. What is meant by a *converter* or *transformer?* Sketch the details of any well-known form. [Ord. 1890.]

8. What is meant by saying that a certain transformer has an efficiency of 98 per cent.?

9. What thickness of sheet-iron would you use (1) in direct-current armatures, (2) in alternators, (3) in transformers? How are the sheets cut up into pieces of the right size and shape, and how are the pieces then dealt with for the building up of a core? [Ord. 1898.]

10. What losses in transformers are affected by the lamination of the core? State how they are affected, and why? [Ord. 1902.]

11. Describe, by the aid of sketches, an alternate current transformer of the shell type, and mention all the important points to be taken into account in designing transformers for ordinary lighting loads. [Ord. 1902.]

12. The core of a transformer (alternate current) contains 100 square centimetres nett sectional area of iron. Assume that it is to be used on a circuit in which the frequency is 75 complete periods a second, and that the primary currents supplied will be such as to raise the magnetic induction at each alternation to 5000 lines (C.G.S.) per square centimetre. Find how many turns there must be in the secondary coil if it is to produce 100 volts on open circuit. [Ord. 1893.]

13. Point out in what way the pressure at the secondary terminals of a good transformer depends on that at the primary terminals and on the respective number of windings and their resistance. A transformer with a well-closed magnetic circuit is taking 10 amperes at 2,050 volts. Its primary coil consists of 860 turns of wire having a total resistance of five ohms. Its secondary consists of 43 turns, with a resistance of $\frac{1}{80}$ of an ohm. Assuming that magnetic leakage, eddy currents, and hysteresis are negligibly small, calculate the pressure at the secondary terminals when 200 amperes are being supplied to the lamps. [Ord. 1896.]

*14. Explain the principle of the motor-dynamo.

15. What is a rotary converter, and what is its principal use? Explain generally why the output of a rotary converter may be rated at a higher value than a direct-current dynamo of the same size. [Ord. 1899.]

16. What rules govern the design of motor-generators? Upon what does the speed of them depend? [Ord. 1894.]

17. Describe in detail how you would wind a motor-dynamo, fed at constant pressure, to give constant pressure between the secondary terminals. [Ord. 1897.]

18. What are the advantages of separate field magnets for the two armatures in continuous-current transformers? [Ord. 1895.]

19. An alternate current transformer is supplied at constant P.D. on the primary, and the secondary is gradually loaded with lamps to 50 per cent. overload. Show by curves how (*a*) the primary current, and (*b*) the secondary P.D. vary as the load increases. State also how these curves would be altered if the load were highly inductive. Give reasons for your answers. [Ord. 1903.]

CHAPTER XVII.

The figures refer to the numbered paragraphs.

Chapter, paragraph, and figure numbers in italics refer to Vol. I. (5th Ed.), and those in heavy type to "Electric Wiring, Fittings, Switches, and Lamps" (3rd Ed.).

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*210. ELECTRIC GENERATING STATIONS.—An *electric generating station* is a place where mechanical energy is transformed into electrical energy. This is effected by means of alternators or dynamos driven by steam- or gas-engines, or—where water-power is available—by turbines. The electrical energy thus generated is then conveyed by means of a *feeding* and *distributing system* of copper cables or mains through the streets to the premises of the private consumers, to the street lamps, and to the tramway or railway systems.

A generating station is frequently termed an *electricity works,* from the analogous term "gas works." It is also sometimes referred to as a *central station,* because very often the most suitable place in which to put it, if space can be found, is in the centre of the district to be supplied.

*211. ELECTRICAL ENERGY.—Electrical energy has the capability of doing electrical work, and is measured by taking the product of the electrical power and the time the power is maintained. The commercial units of electrical energy or work are the *watt-hour* and the *kilowatt-hour,* electrical power being measured in watts. As the power (in watts) is equivalent to the pressure multiplied by the current, electrical energy is otherwise proportional to the pressure, current, and time multiplied together.

It is possible to convey a given amount of electrical energy either as a small current at high pressure, or as a large current at low pressure. For instance, a current

of two amperes flowing for one hour at a pressure of 4000 volts, represents the same amount of energy as a current of 40 amperes flowing for one hour at a pressure of 200 volts; each giving 8000 watt-hours, *i. e.* 8 kilowatt-hours, or 8 B. o. T. or supply units (Chap. *II.*).

*212. PRESSURE OF SUPPLY, AND THE SIZE AND INSULATION OF MAINS.—The size or cross-sectional area of a conductor determines the current it can carry with a fixed drop of pressure; but its current-carrying capacity is independent of the pressure at which the current may be generated or supplied. The cost of copper in the mains is one of the chief items to be considered in laying down a system of supply. Now as power = pressure × current, in the transmission of a given amount of power, the current flowing in the conductors is reduced as the pressure is increased; and reduction of the current means that conductors of a smaller size may be used. Hence, other things being equal, the greater the pressure at which the supply is generated, the greater the saving of copper. On the other hand, however, the higher the pressure the greater the care required to maintain the insulation; and a better quality of and thicker insulating covering has to be given to all the parts of the conducting system (§ 242).

*213. MAINS, CURRENT, AND DROP.—The size of a main is determined by two leading considerations. Firstly, the maximum current it has to carry, and secondly, the greatest permissible drop of pressure between the supply and consumption ends. The first consideration has reference to the heating of the conductor due to the watts wasted in it, and is determined by the Board of Trade Rule, which insists that the conductors shall at no time rise more

than 30° F. beyond the outside or normal air temperature. Experiments by Mr. C. H. Yeaman on the mains at Liverpool, some years ago, showed that at full load they rose to a final temperature of 28° F. above the external air, this being just within the prescribed limit.

The highest current density ever permissible is determined by a Rule formulated by the Institution of Electrical Engineers. Tables giving the various sizes of conductor, and their maximum allowable currents calculated in accordance with this rule, as well as the rule itself, will be found in the Author's *Electric Wiring Tables.* The currents permitted by this rule are not in proportion to the cross-sectional area of the conductor; it being rightly assumed that small conductors have greater facilities for cooling than larger ones, so that the former may safely be allowed to carry more current in proportion to their area than the latter. For small and medium sizes the permissible currents are greater, and for large sizes slightly less, than those calculated according to the old "1000 amperes per square inch" rule.

Many people, however, still work to the latter, and it is convenient to remember that, at this uniform density of 1000 amperes per square inch, the pressure-drop for all sizes is about 4·8 volts per 100 yards run of double conductor, that is of lead and return. The drop varies directly with the current density, and also directly with the length of the conductor; so that calculations can be made rapidly, without it being necessary to find the resistance of every conductor used.

For example, 300 yards of double conductor main, worked at 500 amperes per square inch, would experience a drop of:—

$$4{\cdot}8 \times \frac{300}{100} \times {\cdot}5 = 7{\cdot}2 \text{ volts.}$$

Here we multiply by ·5, as we are working at half the standard density. If the current be tapped off uniformly at equidistant points along a cable, the drop is only half that resulting from the current being taken off all at one end, since the average current flowing is halved. Thus in the example just given, the drop would be just above 3½ volts if equal currents were tapped off at, say, every 20 yards along the length of the cable.[1]

The rise of temperature in a conductor must be kept within limits, not only because such heating would tend to lower and damage the insulation, but also because it would increase the resistance, and therefore also the drop.

214. ECONOMY OF HIGH PRESSURE.—The advantages of high over low pressure depend chiefly on the fact that the loss of power in a given cable is proportional to the square of the current. In other words, the watts lost in any cable at any pressure are simply proportional to C^2R, where C is the current in and R the resistance of the cable.

The effect of increasing the voltage is illustrated by the following examples. In the first of these is shown the result of doubling the voltage while transmitting the same power through a double (lead and return) cable.

Case A. At 1000 amperes per square inch density :—

(*a*) A $\frac{19}{14}$ cable will carry, say, 100 amperes.

[1] Various rules and numerous worked examples relating to pressure-drop will be found in the last chapter of the Author's *Electric Wiring, Fittings, Switches, and Lamps.* Tables of pressure-drop are given in the Author's *Electric Wiring Tables.*

(*b*) With a P. D. between lead and return of 100 volts,

(*c*) The power conveyed will be 10,000 watts.

(*d*) The drop per 100 yards run will be 4·8 volts,

(*e*) And the percentage-drop :—

$$\left(\frac{4{\cdot}8 \times 100}{100}\right) = 4{\cdot}8 \text{ volts.}$$

(*f*) The watts lost per 100 yards will be $4{\cdot}8 \times 100 = 480$,

(*g*) And the percentage loss of watts per 100 yards :—

$$\frac{100 \times 480}{10{,}000} = 4{\cdot}8.$$

On doubling the pressure, but still transmitting the same power, the current density will be halved. Then :—

Case B. At 500 amperes per square inch density :—

(*a*) A $\frac{19}{14}$ cable will carry 50 amperes.

(*b*) With a P. D. between lead and return of 200 volts,

(*c*) The power conveyed will be 10,000 watts as before.

(*d*) The drop per 100 yards run will be 2·4 volts,

(*e*) And the percentage-drop :—

$$\left(\frac{2{\cdot}4 \times 100}{200}\right) = 1{\cdot}2 \text{ volts.}$$

(*f*) The watts lost per 100 yards will be $2{\cdot}4 \times 50 = 120$,

(*g*) And the percentage loss of watts per 100 yards run :—

$$\frac{100 \times 120}{10{,}000} = 1{\cdot}2.$$

Thus by doubling the pressure, and sending the same power through the same cable, we quarter the loss of power in it, and reduce the percentage-drop and percentage loss of power to one-fourth. Or, to illustrate the advantage another way, we can transmit a given quantity of power *four times as far* (with a fixed percentage-drop and loss) by using twice the original voltage.

Usually, however, it is not required to reduce the current density in the cable. Thus, in the following example, the density remains the same in either case.

Case A. With a supply pressure of 100 volts, and a density of 1000 amperes per square inch :—

(*a*) A $\frac{19}{14}$ cable will carry 100 amperes.

(*b*) The power conveyed will be 10 kilowatts.

(*c*) The drop per 100 yards run will be 4·8 volts,

(*d*) And the percentage drop :—

$$\frac{4{\cdot}8 \times 100}{100} = 4{\cdot}8 \text{ volts.}$$

(*e*) The watts lost per 100 yards run will be $4{\cdot}8 \times 100 = 480$,

(*f*) And the percentage loss of watts per 100 yards run :—

$$\frac{100 \times 480}{10{,}000} = 4{\cdot}8.$$

Case B. With a supply pressure of 200 volts, and a density of 1000 amperes per square inch :—

(*a*) A $\frac{19}{14}$ cable will carry 100 amperes.

(*b*) The power conveyed will be 20 kilowatts.

(*c*) The drop per 100 yards run will be 4·8 volts,

(*d*) And the percentage drop :—

$$\frac{4{\cdot}8 \times 100}{200} = 2{\cdot}4 \text{ volts.}$$

(*e*) The watts lost per 100 yards run will be $4{\cdot}8 \times 100 = 480$,

(*f*) And the percentage loss of watts per 100 yards run :—

$$\frac{100 \times 480}{20{,}000} = 2{\cdot}4.$$

Thus we see that by keeping the current density constant, we can convey twice the power by doubling the voltage. The percentage drop and the percentage loss of watts, however, will be only half their previous values.

Here is another example showing that by using double the pressure, the same power, at the same current density, can be conveyed by a cable half the size, and with half the C^2R loss.

Case A. With a pressure of 100 volts, and a density of 1000 amperes per square inch in the conductor, a power of, say, 50 kilowatts would require a cable of $\frac{50{,}000}{100 \times 1000} = {\cdot}5$ square inch sectional area.

Case B. With a pressure of 200 volts, and a density of

1000 amperes per square inch in the conductor, 50 kilowatts would require a cable of $\frac{50{,}000}{200 \times 1000} = \cdot 25$ square inch sectional area.

Had the resistance of the cables remained the same, the C^2R or *wattage loss* would have been one-quarter what it was in the first case; but since the resistance of the second cable is double that of the first cable, the C^2R loss is half its previous value. As the current density is the same in each case, so also will be the "drop" for any given length; but the percentage drop will obviously be halved.

In distribution work, especially at low pressures of 100 volts or so, it is seldom that cables are worked at a greater density than 500 amperes per square inch, in order that the loss therein may be kept within a reasonable limit. The fact that there was plenty of margin for increasing the current without overheating the conductors explains how it was that many supply companies in recent years, by both doubling their pressure and doubling the current density in their cables, were enabled to *quadruple* the carrying capacity of their mains. The following example illustrates this.

The pressure at which current is supplied to houses on a distributing network is raised from 110 to 220 volts. By how much per cent. will the carrying capacity of the mains be increased, if the percentage loss of volts in them is to remain the same as before,—it being presumed that the cables have such a large margin of conductance that the question of heating may be neglected?

The percentage loss is to be the same; consequently, the pressure having been doubled, the current must

be increased until the original percentage loss is reproduced.

The percentage loss of volts in a circuit is directly proportional to the current, and inversely proportional to the pressure. Thus:—

$$\text{percentage loss} \propto \frac{C}{V}$$

where C stands for the current, and V for the volts on the circuit.

In the present case, call the original loss y per cent., with a current C_1 at 110 volts. It is required to find a current C_2 at 220 volts which will give the same percentage loss. Now:—

$$y = \frac{C_1}{110} = \frac{C_2}{220}$$

$$\therefore \frac{C_2}{220} = \frac{C_1}{110}$$

so that:— $$C_2 = \frac{220}{110} C_1 = 2C_1.$$

That is to say, the current-carrying capacity of the mains will be doubled, or increased by 100 per cent. Their power capacity, however, will be quadrupled, *i. e.* increased by 300 per cent. In other words, if we double the pressure, we keep the percentage loss the same by doubling the current, because we get twice the drop, and:—

$$\frac{\text{twice original drop}}{\text{twice original pressure}} = \text{same percentage loss.}$$

Thus four times the power is transmitted with the same percentage loss of volts, because twice original pressure ×

twice original current = four times original power. Hence, as far as current is concerned, the carrying-capacity of the mains is doubled; but the pressure being also doubled, the wattage or lamp-feeding capacity is quadrupled.

The loss in a cable may be expressed either as power, as in watts or kilowatts; or as energy lost in a given time, as in watt-hours or B. o. T. units per day, month, or year.

Besides the C^2R or *copper loss,* there is another loss to be considered in alternating-current systems of supply. This is due to induced or eddy currents in neighbouring conductors or masses of metal, which draw their supply of inducing energy from the conductors through which we are sending our current. The estimation of these *eddy current, induced current*, or *Foucault current losses,* as they are variously termed, is beyond the elementary student. It may be mentioned, however, that unless properly guarded against, they can easily exceed the ordinary C^2R losses in amount. If a single cable conveying an alternating current were placed by itself in an iron pipe, we should get a very aggravated case of eddy current loss, not to speak of the inductance set up; but only a lunatic would do this sort of thing.

*215. HIGH- AND LOW-PRESSURE SYSTEMS.—The methods of distribution adopted by most of the electricity supply undertakings may be divided into three classes, according as they are low, high, or extra high pressure. These may again be classified as alternating or direct, as the one or the other current is supplied to consumers. The choice of the method of distribution is governed principally by the district which is to be supplied, and to some extent by the ideas of the engineer responsible for the work. If the

central station can be placed in the centre of its district, and if the district be small and compact, then a low-pressure system may be adopted. If the district, though small, had outlying parts, or scattered consumers, then the system would preferably be a high-pressure one. If the district were very large, and were supplied from a single central station; or if the central station were situated a great distance away from its district, then an extra high-pressure system of supply would have to be resorted to.

*216. SYSTEMS OF SUPPLY.—Systems of supply are either *direct* or *converted* according to the relation between the supply pressure and the pressure at which the generators work. If the conditions referred to in the preceding paragraph necessitate the adoption of extra high pressure, then alternators and transformers must of necessity be employed, because of the difficulty of constructing a commutator for such voltages. For a high-pressure system, either alternators and transformers, or high-pressure direct-current dynamos and motor-dynamos (direct-current transformers) may be used; while in a low-pressure system, untransformed direct currents are generally adopted.

In no case may the supply enter a consumer's premises at a greater pressure than 250 volts between a single pair of conductors or terminals, without the sanction of the Board of Trade; and it is for this reason, among others, that transformers have to be used on high-pressure systems. The special sanction is extended to large users of motive power, and allows of a pressure up to 500 volts. The maximum supply pressure of 250 volts is used on two or three systems, but the pressures mostly employed are 240, 230, 220, 210, and 200 volts. A few years ago the

general supply pressures were 100, 105, or 110 volts; but such are used in very few districts now-a-days.

*217. CLASSIFICATION OF SYSTEMS.—Systems of supply may be classified as follows:—

(I.) Those that supply through feeders and mains direct to the distribution network, and

(II.) Those which supply through feeders and transformers to the network.

A more complete classification of systems would be as follows:—

I. DIRECT SUPPLY.

(*a*) Direct currrent on 2-wire system (§ 219).
(*b*) „ „ „ 3-wire „ (§ 222).
(*c*) „ „ „ 5-wire „ (§ 229).

II. TRANSFORMED OR CONVERTED SUPPLY.

(*d*) Direct current with motor-dynamos (§ 232).

(*e*) „ „ „ „ „ and secondary batteries in transforming stations.

(*f*) Alternating current with static transformers (§ 233).

(*g*) Polyphase currents with motor-generators (alternating to direct) in sub-stations (§ 239).

What are known as *mixed systems* may embody a combination of two or more of the above. The most common mixed system is that in which direct current is supplied for the centre of the district, and for tramway working; and alternating current for outlying parts. It is on such systems that double-current generators (§§ 79 and 79A) may be employed, the machines being used to give either direct or alternating current as required.

*218. FEEDERS AND DISTRIBUTORS.—The essential point in designing or mapping out a system of mains is to maintain a uniformity of pressure. Subservient only to this, the central station engineer has to set out his distributing system so that it is reasonably low in first cost, and he has also to keep the loss (in watts at full load) as small as possible. In a badly-designed system, the number of Board of Trade units lost (*i. e.* wasted as heat) in the mains per annum, may reach a very considerable and extravagant figure.

Mains may be divided into two classes: feeders and distributors. *Feeders* are conductors which radiate from the generating station to various distant points, where they are connected, either directly or through transformers, with the *distributors* or distributing networks which supply the current to the buildings, etc.

A feeder may have a comparatively large drop of volts in itself without affecting the uniformity of pressure in the distributors, because the pressure is kept constant at the point where it joins the latter. Thus a feeder may have a drop of 20 volts on a 240-volt direct system; but nowhere in a distributor should the pressure fall more than, say, 3 volts below that at the feeding point.

*219. DISTRIBUTING MAINS.—Reversing the usual order of things, it may help matters if we begin our consideration of the different systems of distribution at the consumers' *service wires.* The latter are wires connected with the nearest convenient points on the distributing network, and passing into a consumer's premises. As a rule only two wires are brought in, but sometimes, if the consumer intend to use a great deal of current, and the mains are

on the 3-wire system (§§ 223 to 226), three service wires are taken into the building. The methods by which the lamps, etc., are connected to the service wires do not concern us here, but will be found fully set forth in Chap. **III.**

Considering the usual condition of things, in which two service wires are taken in to each consumer, the way they are connected to the mains in a street is shown in Fig. 348, where *C*, *C*, *C*, etc., represent the consumer's premises, *S*, *S*, *S* the pairs of service wires, and *M*, *M*

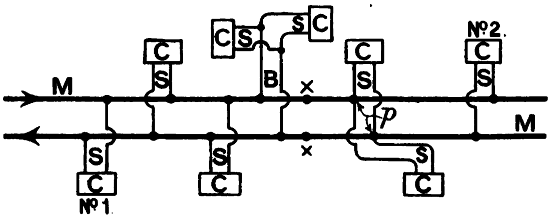


FIG. 348.—Connection of Service Wires.

the distributing mains. Very often, as at *p*, two or more sets of service wires may be connected to the mains at one point. Or in the case of a side-street, a branch *B* would be taken off *M*, and consumers joined-up thereto. Service wires are connected to the mains through *service boxes,* of which there are many different patterns. Sometimes the latter are in the nature of underground distribution boards, two or more consumers being joined-up to one box.

The very simplest kind of distribution network would be somewhat as in Fig. 349, where *M*, *M*, *M*, *M* are pairs of mains radiating from a central point *P*; and *C*, *C*, *C*, etc.,

the consumers connected thereto. On a very small and compact system *P* would be (i) the generating station itself. On a larger one it might be (ii) a *feeder point,* to which a pair of feeders *F* proceeded straight from the distant

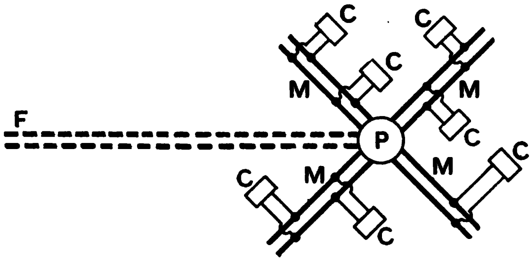


FIG. 349.—Simple Distribution Network.

generating station: or, on a still larger system, (iii) a *transforming station* in which a high-pressure current coming along the feeder *F* was transformed down to the proper supply pressure. On a very large system *P* might be (iv) a *sub-transforming station* connected through *F* with a larger transforming station; the latter in its turn being connected with the generating station.

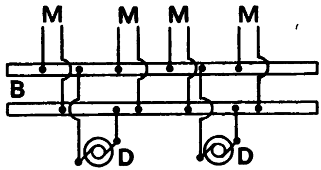


FIG. 350.—Connection of Dynamos and Mains to Bus-Bars.

In case (i) *M, M, M, M* would be run direct to bus-bars *B,* into which one or more dynamos *D, D* fed, as in Fig. 350; while in case (ii) they would be connected with the ends of the feeder as in Fig. 351. In cases (iii) and (iv) a transformer, or set of transformers, would form the link between *M, M* and *F.*

The four cases cited above may be diagrammatically represented as in Fig. 352, where at (*a*) *G* represents a generating station supplying the distribution mains *M*, *M*, *M*, etc. At (*b*) *G* is the generating centre, and *F*, *F*, *F*, *F* feeders running to various feeding points *P*, *P*, *P*, *P*, where they are connected, either directly or through transformers, to the distributors radiating therefrom. In (*c*) *G* is the generating

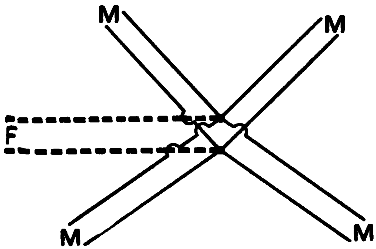


FIG. 351.—Connection of Mains to Feeder.

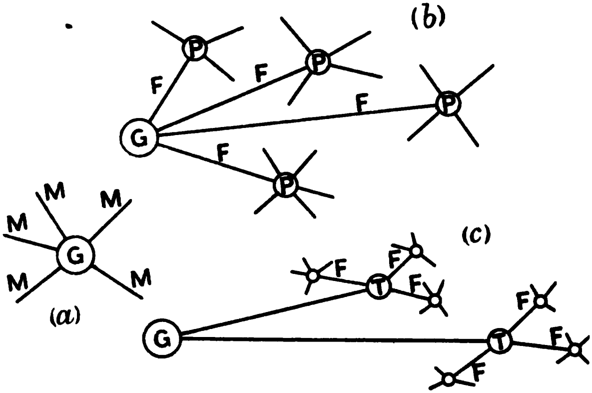


FIG. 352.—Connection of Generating Station with Transforming or Feeding Points.

station, *T*, *T* transforming stations, and *F*, *F*, *F*, etc., feeders running to feeding points as before. In these diagrams each pair of conductors is represented by a single line.

It should be noted that feeder cables pass direct from the generating or transforming points to the feeding points without any intermediate connection being made to them. With distributing cables, on the other hand, branch cables or service wires are taken off at numerous points *en route.* Then again, although it is hardly necessary to say so, neither feeders nor distributors run along such convenient straight lines as the figures represent, but turn and twist in most tortuous fashion through the various streets. Also, as will be seen later on, the distributing mains round one feeder point are usually connected with those of neighbouring feeder points. Indeed the distributing system is frequently in the form of a continuous network.

The simplest way to supply a street with current is to carry a pair of conductors down it, and to connect these conductors at one end only with a feeder point, or with the larger distributing mains. Thus in Fig. 348, we will suppose that the supply enters at the left-hand end. Now it is obvious that there will be a fall of potential from left to right, so that if the consumers in the street be numerous, consumer No. 2 at the far end will, unless the mains are of extravagant thickness, get noticeably less pressure at his lamps than consumer No. 1. In such a case, the drop is considerably reduced by making the connection midway along the street main, as at the points XX. As a matter of fact, supposing the main were uniformly "loaded" with consumers from end to end, the limits of drop, when the connection with the distributing network was made at the middle, would be only one-fourth as great as when the connection was made at one end (see Example in Chap. **IV**.). Another way of equalizing the drop of pressure

is shown in Fig. 353, one of the mains being taken to the end of the street and then bent back. In this arrangement the pressure at each end will be about equal, and will be least at the centre, the service wires *S, S, S* being connected to the free part of the bent main.

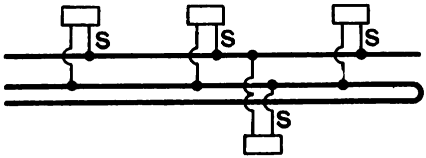


FIG. 353.—Equalizing the Pressure-Drop.

When a street main is supplied at one end only, as the current gradually falls off from a maximum at the supply end, to a minimum at the other end, it is sometimes unnecessary to continue the same cross-section of conductor throughout the entire length. Thus at various convenient junction points the size of the conductor may be reduced step by

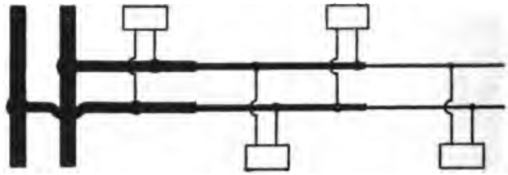


FIG. 354.—Reducing Size of Main.

step as indicated in Fig. 354. This, however, can only be done when the loss of volts at the far end does not exceed the permissible limit; and when the loss of power in the cable is compensated for by the saving in copper.

Although the "tree" system of wiring, as illustrated by Fig. 348, must of necessity be adopted at some points in a distribution network, it is better to put restriction upon its

use, and to take off branches and services from connecting and service boxes, which fulfil exactly the same purpose as the main and branch distribution boards used in interior wiring (Chap. **III.**) Thus in Fig. 355, the branch mains *B*, *B*, *B* are taken off at a common point *P* in a larger pair of mains *M*, and the service wires *S*, *S*, *S* at *p*.

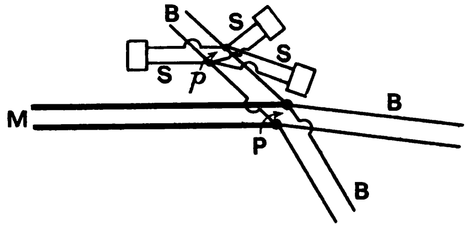


FIG. 355.—Grouping of Branch and Service Mains.

***220. RING OR LOOPED MAINS.**—Supposing there are branch mains running down parallel or adjacent streets, it is of considerable advantage to loop their free ends together. Thus in Fig. 356, M_1 and M_2 are branch mains in neighbouring streets, which derive

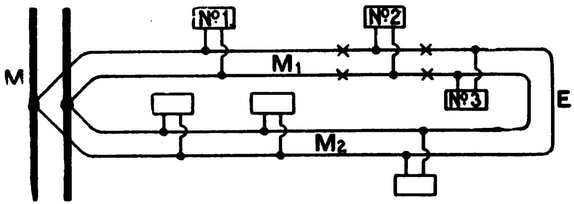


FIG. 356.—Ring or Looped Mains.

their supply from the larger mains *M*, and have their ends looped together at *E*. In this way greater security from breakdown is assured, as the current has the choice of two routes to any of the consumers. Then again, any section can be cut out for repairs, etc., without affecting the supply

on either side. Thus if a section *X X X X* be cut out, only consumer No. 2 is affected, No. 1 getting his supply from the left, while No. 3 is supplied through the loop *E*. This is a simple illustration of the principle of what are known as *ring* or *looped mains*. A more extensive application is illustrated in Fig. 357. Here *M*, *M* are large distributing mains traversing the principal streets in the heart of a town, and fed from the feeder points *F*, *F*. At *P*, *P*, *P*, etc., branch mains as in Figs. 348, 353, 354, 355, or 356 are taken off to supply side-streets.

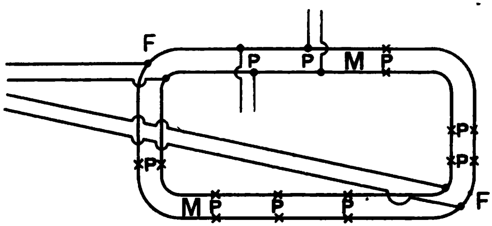


FIG. 357.—Ring Mains.

221. CONTROL OF PRESSURE ON TWO-WIRE FEEDERS.—Referring to Fig. 352, it is necessary to keep the pressure at each of the feeder points constant. Thus on a 240-volt system, the pressure would have to be kept at, say, 243 or 244 volts, it being reduced, by the time the consumers' lamps were reached, to the standard value, viz. 240 volts.

The pressures at the feeder points are usually indicated at the central station by voltmeters connected with the distant ends of the feeders through *pilot wires*. Sometimes all the feeders are connected at the station to bus-bars kept at a constant pressure. Now, the loss of pressure in long feeders is greater than that in short ones, and so a difficulty arises.

This may be got over in various ways. In one method, the pressure at the bus-bars is made great enough to give the right terminal pressure at the ends of the longer feeders; while the terminal pressure of the short ones, being then too great, is reduced by inserting one or more secondary cells in opposition at the generating station end, the E.M.F. of these being contrary to the supply E.M.F. Another method is to insert boosters either at the station, or at the distributing ends of the long feeders; these having the effect of slightly raising or "boosting-up" the pressure to compensate for the extra drop. The action of such a booster was explained in § 204. Or ready-charged cells may be inserted at the station end so that their E.M.F. helps the bus-bar E.M.F.

These methods are only applicable on direct-current systems. In alternating-current work, the pressure-drop in a feeder may be increased or diminished by means of a static booster or a regulable transformer, as explained in § 197; or by altering its impedance by means of a large choking coil similar to those in Figs. 68 and 69.

Another way of dealing with the varying drop on feeders in direct-current systems, is to have multiple bus-bars at slightly different pressures; the long and short feeders being connected to the bars at the higher and lower pressures respectively (§ 233).

*222. THE THREE-WIRE SYSTEM.—The diagrams that have been given in this chapter so far, illustrate the 2-wire system of distribution. Now-a-days, however, only small supply systems are on this principle throughout. In large ones only the smaller branches of the distributing network are 2-wire; the larger or main distributors being 3-wire.

A considerable saving in copper results from the adoption of the 3-wire system, which permits the use of a pressure on the distributing mains double that required at the lamps. The advantages of high pressure are briefly as follows. The load on a circuit is expressed in kilowatts, and any given amount of power may be conveyed in the form of a large total current at low pressure, or as a small total current at high pressure. Now a large current means plenty

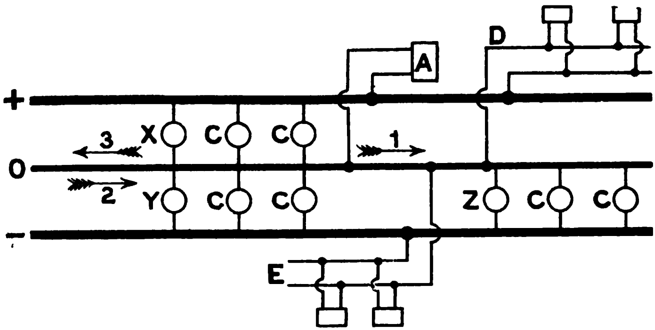


FIG. 358.—The Three-wire System.

of copper in the cables, while a high pressure necessitates good insulation; and, all things considered, well-insulated copper cables of low conductance are cheaper than ordinary insulated ones of high conductance. With a fixed current density, cables at, say, 200 volts will carry twice the power if the pressure be increased to 400 volts; and four times the power if both the current and the pressure be doubled, the current density of course being also doubled in this case. This matter, by the way, was fully entered into in § 214.

Fig. 358 represents a portion of a 3-wire distributor, the middle wire being termed the *neutral* or *balancing wire.* This middle wire need only have half the cross-section of the "outers," as it is only required to carry current when the demand on one side exceeds that on the other. We may conveniently distinguish the three mains by the signs $+$, 0, and $-$; $C, C, C,$ etc., representing consumers supplied by the mains, some being connected between $+$ and 0, and some between $-$ and 0. The former is termed the positive side, and the latter the negative side of the system.

Let us first consider how this arrangement of conductors results in the saving of copper. Suppose we have to deal with a load (lamps, motors, etc.) equivalent to 100 kilowatts. On a 2-wire system at, say, 245 volts, this means that each cable must carry about 408 amperes. With three cables, the same load can be dealt with at double the pressure, *i.e.* 490 volts; so that the maximum current will then be 204 amperes. Neglecting the middle wire, the amount of copper in the mains would thus be reduced to exactly one-half: but taking the middle wire into account, this having half the section of either "outer," *i. e.* a carrying capacity of 102 amperes, the reduction is to five-eighths. For with a 2-wire distributor, the total cross-section of the cables is equivalent to $2 \times 408 = 816$ amperes; while with 3-wire distributors the total cross-section is equivalent to $2 \times 204 + 102 = 510$ amperes. Thus, copper in 3-wire system : copper in 2-wire system

$$: : 510 : 816 = \text{five-eighths.}$$

The actual saving of copper, however, is generally greater than this, for, as will be seen later on (Figs. 360 and 368),

it is possible, under certain conditions, to feed into the 3-wire distributors with 2-wire feeders connected to the outers; the saving of copper in the feeders being then very considerable. In fact, taking both feeders and distributors into consideration, the outlay on copper is often reduced to nearly one-half.

With 3-wire distributors, the load has to be as equally divided as possible between the two sides of the system. The duty of the middle wire is to make up for the want of balance on either side, and it performs this by taking current into or sending it out from the generating or sub-station, or feeder point, as required. It has also to carry current from one part of the system to another, as when a heavily-loaded portion on the + side is some distance from the equivalent load on the − side, or *vice versâ*.

In Fig. 358 there are three groups of consumers, *X*, *Y*, and *Z*. In the first instance, we will suppose that only groups *X* and *Y* are taking current, and that the demand by each is exactly the same. Under these conditions there would be no flow of current along 0 to or from the station or feeder point; and since the connections of groups *X* and *Y* are exactly opposite, there would be no flow of current at any part of 0. In practice, however, such perfect balance never exists. Secondly, we will assume that the load on each side is equal, and that it consists of groups *X* and *Z*. In this case there would be no flow of current along 0, inwards or outwards, to or from the source of supply; but there would be a flow from *X* to *Z* as indicated by the arrow *1*. Next, suppose the load be unequal, all three groups *X*, *Y*, and *Z* being in circuit. Under these circumstances, the supply of current passing

through X will be too small for Y and Z; and a current sufficient to make up the deficit will flow outwards along 0, as indicated by the arrow *2*. If, lastly, the load on the + side be greater than that on the − side; the balance of + current that is not required by the − side will flow inwards to the source, as indicated by the arrow *3*.

In Fig. 358, for simplicity's sake, the service wires of the consumers C, C, C, etc., have been drawn between the mains, instead of outside as at A. A 3-wire distributing network is seldom 3-wire throughout; 2-wire branches, as at D and E, being taken off either side to supply consumers in by-streets. This does not alter the principle of the system, however.

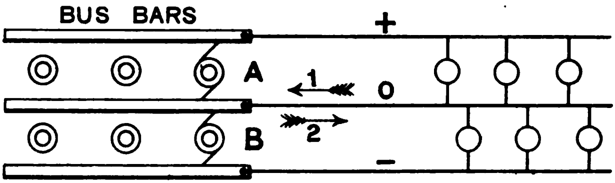


FIG. 359.—The Three-wire System.

223. SIMPLE APPLICATIONS OF THE THREE-WIRE SYSTEM.—There are several different methods of applying the 3-wire system, the chief of which will now be described.

(*a*) Originally, the three mains were connected to three bus-bars in the direct-current central station, as depicted in Fig. 359; and dynamos were joined up as shown, extra ones being switched on as required. Provision was made to enable any machine to be put on either the + or − side, as was necessary. If the loads on each side

were equal, no current would flow along the neutral wire, and the dynamos would virtually be working in pairs of two in series. If the + side had the greater demand, the surplus current would flow back along the middle wire to the "*A*" machines, as indicated by the arrow *1*. But if the + had less load than the – side, the extra current required by the latter would flow out from the "*B*" dynamos along the middle conductor, as indicated by the arrow *2*.

In practice, of course, sets of mains would radiate in all directions from the bus-bars, as at (*a*) in Fig. 352. Or

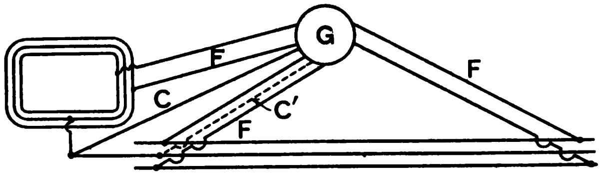


FIG. 360.—The Three-wire System.

3-wire feeders might be led to various points, as at (*b*) in the same figure. The ring system (Fig. 357) is as applicable in 3-wire as in 2-wire work.

(*b*) Although the middle or balancing conductor forms part and parcel of a 3-wire distributing network; where feeders are employed, it is not at all necessary that each of them should contain a middle wire. Thus in Fig. 360, *F*, *F*, *F*, are 2-wire feeders, and the middle wire, being continuous over the whole system, is connected with the neutral bus-bar at the generating station *G* by a single conductor. This may be quite independent of the feeders, as at *C*; or it may form part of one of them, as shown

by the dotted line C'. It does not follow, however, that a single balancing cable would always suffice. On a large network there would be several, which would conveniently be combined with the nearest feeders; so that some of the latter would be 2-wire, and some 3-wire.

(*c*) Where it is permissible to earth the middle wire, a 3-wire network can be formed of two iron-lead-sheathed or lead-sheathed cables (Fig. 361); the copper cores of the

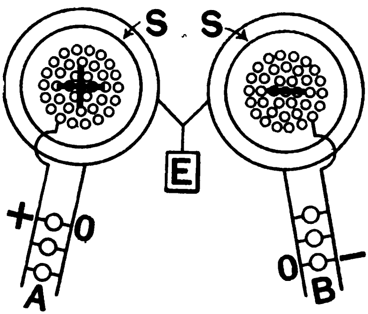


FIG. 361.—Earthed 3-wire System.

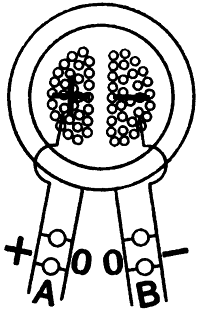


FIG. 362.—Earthed 3-wire System.

cables forming the "outers," and the two sheathings S, S the balancing conductor, the cross section of the iron and lead being sufficient to make up for their low conductivity. In Fig. 361 consumer A is connected between the $+$ cable and its sheathing, and consumer B between the $-$ cable and its sheathing. The fact that the two sheathings form practically one conductor, in connection with earth, is indicated by the earth-plate E. A better arrangement would consist in having a single sheathed cable with two cores, as in Fig. 362.

The saving of copper on such a system would be a maximum, as it would virtually give all the advantages of a 3-wire system, with 2-wire copper feeders and distributors. It is essential of course that all the cables should be armoured, the armouring of the feeders acting as balancing conductors between the station and the distributors. One good point of an earthed system, such as this, is that it lends

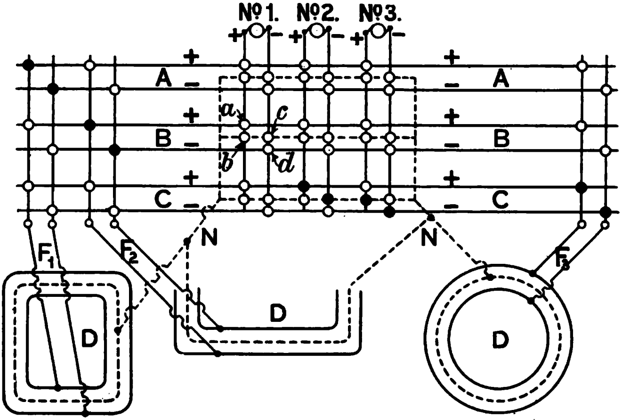


FIG. 363.—Multiple Bus-Bars.

itself to the adoption of concentric house wiring, which latter has much to recommend it, but cannot, unfortunately, be used on other than earthed systems (Chap. III.).

Although such a system of earthed mains is an ideal one in many respects, the Board of Trade regulations do not permit of its use except in very special cases. The system is employed at Guildford, however, the distributors consisting of 2-core concentric cables (§ 242), the armouring of which forms the neutral conductor.

In order to cope the better with unequal loads, and with feeders of various lengths and therefore different drops, multiple bus-bars may be employed. Thus in Fig. 363, *A*, *B*, *C* are three pairs of bus-bars, with vertical cross-bars at the middle and at either end. The middle cross-bars are connected with the dynamos Nos. 1, 2, and 3; and the end ones with the feeders F_1, F_2, and F_3. The feeder bars are 2-wire only, but the centre portion of the lines of "buses" is arranged with centre or neutral bars, as

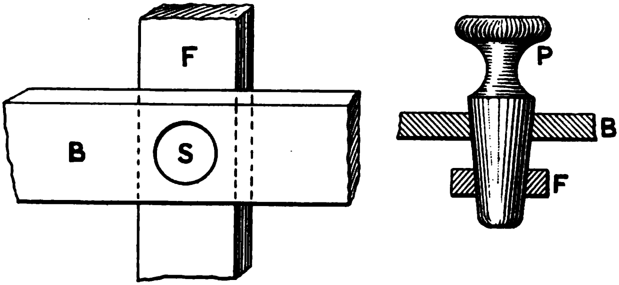


FIG. 364.—Bus-Bar Socket and Plug.

shown by the dotted lines; these being connected with the middle wires of the distributing networks *D*, *D*, *D*, through cables *N*, *N*. Thus 3-wire feeders are dispensed with, the possibility of which was explained in connection with Fig. 360.

The dynamo or feeder bars are connected with any pair of the buses at will by means of plug switches, the principle of which will be gathered from Fig. 364. Here *B* is a bus-bar, and *F* a feeder or dynamo bar behind it, *P* a contact plug, and *S* a contact socket. The sockets and plugs are often threaded, so that a more certain contact between the bars is made by the screwing-in of the plugs.

In Fig. 363 the buses and cross-bars are indicated by single lines only, and the small circles indicate the plug sockets. The circles that are filled in black are meant to denote that plugs are inserted. Thus it will be seen that F_1 is connected with the "A" buses, F_2 with B, and F_3 with C. It will also be evident that any feeder may easily be connected with any pair of buses at will.

With regard to the dynamos, the plugging arrangements not only enable any given machine to be connected with any of the sets of buses; but also on either the positive or negative side of any particular set at will. Thus referring to No. 1 generator and B buses, if a and c be plugged, the machine will be thrown in on the $+$ side of B; but if b and d be plugged, the dynamo will be on the $-$ side. The illustration shows No. 2 and No. 3 machines plugged in on the $+$ and $-$ sides respectively of the C buses, while No. 1 is out of circuit. On an actual switchboard provision would have to be made for a number of dynamos, as there would be at least two ($+$ and $-$) for every set of buses, and spare ones besides.

The advantages of this arrangement are, firstly, that the different sets of buses can be kept at different pressures; thus A might be at 505 volts, B at 510 volts, and C at 520 volts. Then there would be little difficulty in compensating for the varying drop in the feeders; the short ones being connected with A, the longer with B, and the longest with C. Secondly, as the load altered on either side of any given set of buses, the supply could be altered to cope with it. Thus suppose that when A was fairly balanced, three machines were connected on each side, *i.e.* six in all: if now the load became much greater on

one side, a seventh machine could be plugged in on that side.

224. Three-wire Distribution with Batteries.—(*a*) Fig. 365 illustrates one method of using a secondary battery for balancing the two sides of a 3-wire system. The 2-pole bus-bars, into which one or more dynamos feed

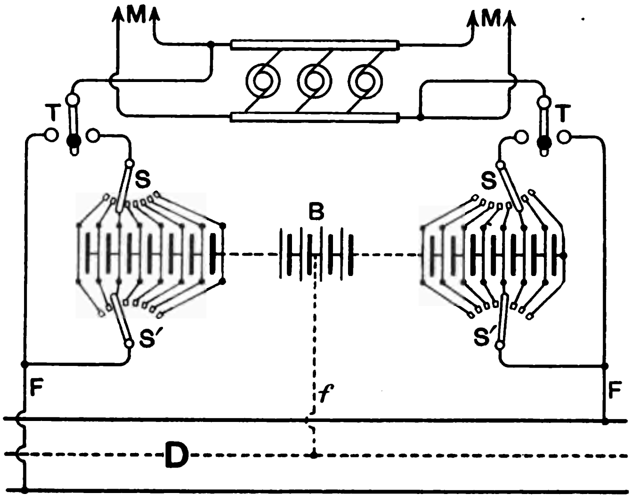


Fig. 365.—Three-wire Distribution with Batteries.

as required, are connected with two-way switches *T*, *T*, by means of which they may be joined up direct either to the outers, or to the ends of a battery *B*. At these ends multiple-way charge and discharge switches *S*, *S*, *S*′, *S*′ form the connection with both the generator and outside circuits, the centre of the battery being connected straight up to the middle wire. The above may form the only

connection with the distributing network *D*: or *F f F* may be regarded as one set of feeders, other batteries and feeders being connected to the bus-bars through other pairs of mains *M, M.*

The 2-way and multiple-way switches give a variety of connections. If the bus-bars be connected directly to

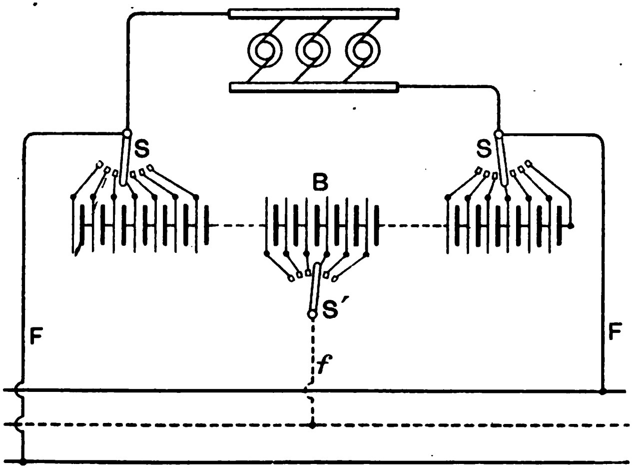


FIG. 366.—Three-wire Distribution with Batteries.

F, F, the full P.D. is thrown thereon. Then the battery will receive charging current through the switches *S′, S″*; but it cannot be of very material use in adjusting the total P.D. between the outers. The P.D. between either outer and the inner, however, may to some extent be adjusted by *S′, S′.* When, on the other hand, the bus-bars are connected direct to the battery through *T, T*; the P.D.

between the two outers, as well as that between either outer and the inner, may be altered considerably.

A great advantage of this, and of most other battery systems, is that at times of light load, the dynamos may be "shut down," and the supply given wholly by the battery.

(*b*) A simpler but less efficient method of using a balancing battery is depicted in Fig. 366. Here the station bus-bars are connected permanently to the outer feeders *F*, *F*, and through multiple-way switches *S*, *S*, with the ends of the battery *B*: the balancing or third wire feeder *f* being joined-up to the centre of the battery, through another multiple switch *S*′. The bus-bar pressure is adjusted to the exact value required by the outers, allowance of course being made for drop; and the switch *S*′ permits of the varying demand on either side being balanced to a nicety. Thus, if the loads on both sides of *f* were equal, the number of cells on either side would also be equal. If, however, there were a greater load on the positive than on the negative side, *S*′ would be so manipulated as to increase the number of cells on the + side, to meet the greater fall of pressure there consequent on the increased current. The switches *S*, *S* enable the number of cells under charge to be altered; and when the load is being run off the cells alone, the P.D. on the outer feeders may be adjusted by their means.

(*c*) Instead of having three regulating switches, the battery may be split in the middle, when two switches will suffice; both of these being connected to the middle wire, in the way depicted in Fig. 367. It should be clear that this arrangement is just as "flexible" in regard to its regulating capabilities as that in Fig. 366. Its advantages are that

the two switches or regulators may be fixed close together on the switch-board, there being no P.D. between them; and that the cost of a third switch is saved.

When batteries are used without charging boosters, as in the above three cases, they are often referred to as *floating batteries.*

225. THREE-WIRE DISTRIBUTION WITH EQUALIZERS OR BALANCERS.—An *equalizer* or *balancer,* sometimes called also a *motor compensator,* is simply a motor-dynamo or direct-current transformer applied to the special purpose

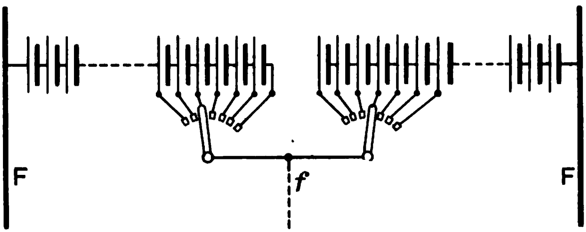


FIG. 367.—Three-wire Distribution with Batteries.

of 3-wire distribution. The principles of motor dynamos were explained in §§ 202 and 203, and it will be remembered that the two sets of armature coils may be wound either on separate cores or on a common core. There are several ways in which such machines may be applied in 3-wire distribution work.

In Fig. 368, C, C' are the commutators of the two distinct sets of coils wound on the armature A, the field F of which may be connected across the mains $M+$ and $M-$, coming from the station bus-bars. These mains are joined-up with the outer distributing mains $D+$ and $D-$,

and with one brush of each commutator; the other brushes being coupled together, and to the balancing distributor *d*. When the loads on the two sides are equal, the pressures between $D+$ and d, and between d and $D-$ will likewise be equal. Under these conditions, a small current, as indicated by the firm arrows, will flow from $M+$ to $M-$ through C and C'; and the machine will rotate, its two windings acting together like those of two motors in series.

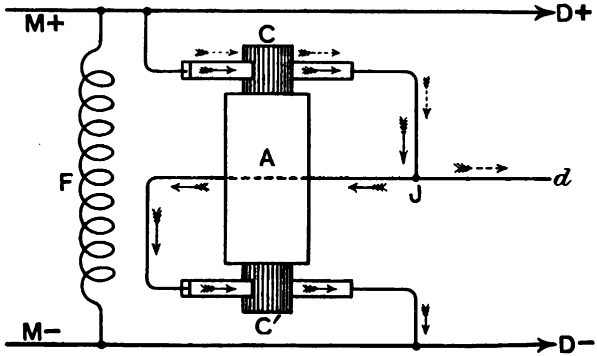


FIG. 368.—Three-wire Balancer or Equalizer.

If the load on the $+$ side preponderate, the P.D. at C will fall below that at C'. The coils connected with C' will then act as a motor armature, and will drive the windings connected with C, generating volts therein, these volts making up the deficit of (or "boosting up") the pressure between $D+$ and d. If the overload be on the $-$ side, C will become the motor end and C' the dynamo end. If the reader think of a balancer in which the armatures are quite separate, as in Fig. 370, instead of

together as in Fig. 368, it may assist him in understanding its action in this case.

Another but cruder way of explaining the action of the balancer is as follows. When balance exists, no current traverses d; and that flowing from the + to the − main through C and C', as indicated by the firm arrows, will simply act motorwise in both armature windings. If, now, an overload exist on the negative side, extra current will be drawn from $M+$ through C and along d, as indicated by the dotted arrows. This extra current, in passing through C's armature, will drive it faster as a motor, and C' will in consequence give out volts to make up for the deficit in pressure between d and $D-$. When the P.Ds. on the two sides of d are again equal, both sides of the balancer will act motorwise as before.

The power absorbed by the balancer is a minimum when the loads on both sides of the system are most nearly equal. Although it is connected across the outers, it must be remembered that the two windings, when acting motorwise, generate a counter E.M.F.; and this has the effect of keeping the current through the machine low.

If the balancer were situated in the generating station, $M+$ and $M-$ would be the bus-bars, and $D+$, d, and $D-$ the distributing mains: and any required number of balancers could be so connected to the buses. This arrangement is generally used, however, when the balancer is placed at a sub-station; in which case $M+$ and $M-$ become the ends of a 2-wire feeder from the generating centre.

Although the Board of Trade rules specify that no greater pressure than 250 volts shall be introduced into

any consumer's premises between any pair of terminals; on a 3-wire system at 400 to 500 volts, all three wires may be led into the building if they are branched off to 2-wire main distribution boards well separated from each other. It may happen, in course of years, that we shall get distribution with, say, 1000 volts between the outers, and 500 volts between each outer and the neutral wire. Then a supply might be led into a street box at 500 volts, and transformed into a secondary 3-wire supply by means of a balancer as in Fig. 368; the two secondary wires on each side, formed by "forking" or splitting the neutral wire, being led to 250-volt distribution boxes, and neighbouring groups of consumers supplied therefrom. Or in the case of a large consumer, the balancer might be placed adjacent to his premises, and the 3-wire secondaries led to two well-separated distribution boards, as above described.

226. THREE-WIRE DISTRIBUTION WITH BALANCER AND BATTERIES.—If, when the balancer is situated at the generating station, feeders instead of distributors were connected thereto, the working would not be satisfactory. In such a case, a battery must be used in conjunction with the equalizer, in one of the two ways mentioned below.

In Fig. 369,[1] E is the equalizer or balancer, which is connected through the multiple-way switches S, S, with the two ends of the battery BA; the mid points of the balancer and of the battery being connected together, and with the third-wire or neutral feeder T at X. Other multiple-way switches S', S', connect the battery with the bus-bars B, B, and with the outer feeders $F+$ and $F-$. The pressure

[1] One of the battery connections has inadvertently been left out of the figure.

between the outers is equal to that between the bus-bars, but the proportion on either side of *T* is regulated by the switches. Thus by moving *S* and *S′* (in the upper half of the figure) in the opposite directions indicated by the two arrows, the P.D. between *F* + and *T* is increased, and *vice versâ*. With any given position of the switches *S*, *S*, and *S′*, *S′*, the conditions in the circuit are these :—A current is continually flowing through the armature wind-

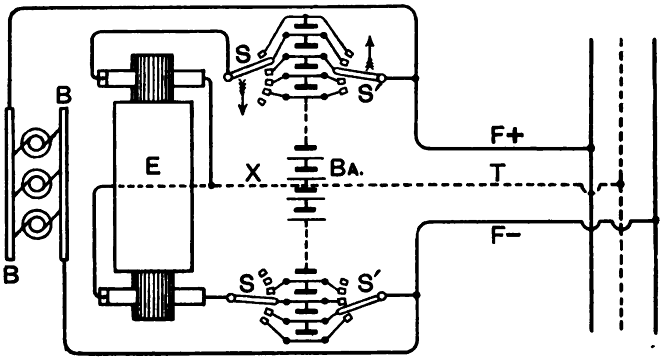


FIG. 369.—Three-wire Distribution with Battery and Balancer.

ings of the balancer, but when the P.D. between each pair of brushes is the same, both windings act motorwise. If the load increase (and the P.D. drop) on one side, that side will generate volts and add them to the circuit, the machine being driven by the excess volts on the other side. The advantages of this arrangement, which should be compared with that in Fig. 365, are that the balancer supplies most of the third wire current, and that the battery may consequently be composed of cells of small

capacity. The "off" stops enable the balancer to be thrown out at times of light load.

A simpler way of arranging an equalizer and a battery, in which the latter need only consist of a few cells, is depicted in Fig. 370. In this method, however, because of the small number of cells, the battery cannot act as the source of supply at times of light load. *E* is the equalizer, this being shown with two separate armature cores for the sake of variation. There are three multiple-way switches;

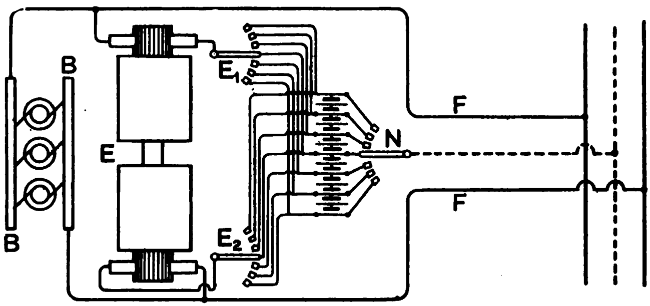


Fig. 370.—Three-wire Distribution with Battery and Balancer.

two, E_1 and E_2, being joined up to the opposite sides of the equalizer, and the third, *N*, with the neutral wire. All three are connected up to the same cells, there being two, four, six, or more cells between each switch contact, according to the gradations of voltage required. The pressure on the outer feeders *F, F* is always that of the bus-bars *B, B*; but the proportion on either side of the neutral wire *N* is adjusted by means of the three switches, but more particularly by *N*; E_1 and E_2 regulating the charging of the cells. If all three switches should happen

to be on corresponding contacts, as in the figure, the battery is out of action, and the arrangement becomes similar to that shown in Fig. 368. In fact the method may be regarded as similar to that shown in the latter figure, but with the addition of a variable number of cells at the junction J. These cells serve to introduce extra counter E.M.F. in the balancer circuit, and so reduce the current through it; the action of the balancer being precisely the same in both cases.

In Figs. 369 and 370 we have represented the connections of the battery and balancer in as simple a manner as possible, and have said nothing about boosters. In § 237 will be found a more complete diagram of the arrangements and connections at a direct-current station, a balancer-booster combination being there employed.

227. THE CHELMSFORD REVERSIBLE BOOSTER.—In § 181 the action of an ordinary battery-charging booster was described, and it was there explained that the sole function of such is to boost-up the bus-bar pressure, and enable the battery to be charged. A *reversible booster* not only does this, but also boosts-up the battery pressure when it is discharging, setting itself automatically to the performance of either duty as the conditions necessitate. In § 237 a non-automatic reversible booster is described.

A simple diagram of one automatic arrangement, known as the Chelmsford or Crompton Reversible Booster, is given in Fig. 371. Here B, B are the bus-bars, and G, G the generators. M is a shunt-wound (and therefore constant-speed) motor connected across the bus-bars, and driving the booster B'. The latter has two sets of exciting coils, e and e', connected in opposition; e forming a shunt

across the battery B'', and e' carrying a part of the main current. The rheostat R, by means of which more or less of the main current may be shunted away from e', enables the relation between e' and e to be adjusted, according to the condition of the cells and of the main circuit.

When the generators are working on their normal outside load, the shunt and series exciting coils of B' are equal in effect; so that no field is set up, and no pressure generated by the booster. Then the battery simply "floats on" the line, it neither charging nor discharging. If

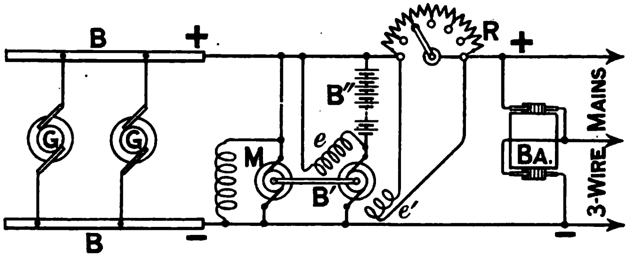


FIG. 371.—The "Chelmsford" Reversible Booster.

the external load, and consequently the current passing through e' increase, the field due to e' will more than counterbalance that due to e; so causing B' to generate pressure, in proportion to the field, in the same direction as that of the battery, which will thereupon discharge and supply the current required for the extra load. When the load decreases, the excitation due to e will preponderate over that due to e'; and B' will then work in opposition to the battery, its counter E.M.F. enabling the bus-bar pressure to send a charging current through the battery. As

already mentioned, the relation of e to e' is governed by R. Thus if it be found, after a few days' working, that the cells do not get sufficient charging; the resistance at R must be decreased, so as to bring e into action more often and with greater effect; and *vice versâ*.

One obvious advantage possessed by this arrangement

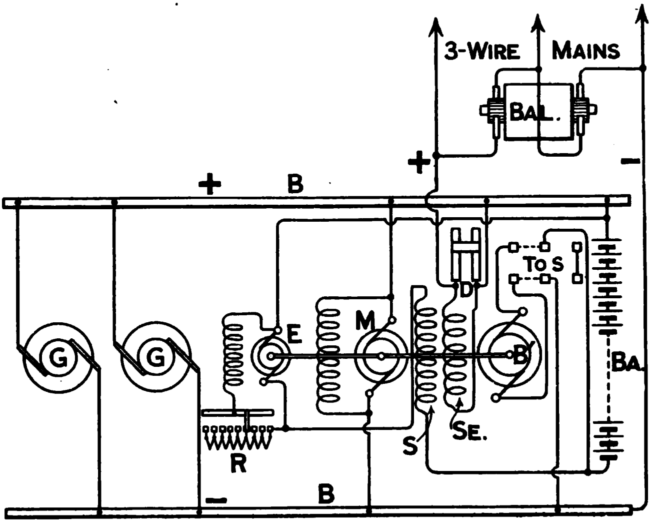


FIG. 372.—The Highfield Reversible Booster arranged for Lighting Work.

is that no regulating cells or switches are required in the battery circuit, so that a less number of cells is necessary. Furthermore, the load on the generators is kept fairly constant, the battery being discharged only at times of heavy load, and charged during periods of light load.

This arrangement may be used to feed a three-wire

system by inserting a balancer at *BA*, this acting as previously explained in connection with Fig. 368.

228. THE HIGHFIELD REVERSIBLE BOOSTER.—This automatic arrangement (Fig. 372) is an improvement on that just described, but it is not quite so simple.

B, *B* are the bus-bars, and *G*, *G* the generators. The booster device consists of three machines, a motor *M*, booster *B′*, and "opposer" or booster exciter *E*. The booster shunt field coil *S* is connected in series with *E*, which provides the exciting current for the former, and the two are joined-up to the ends of the battery *BA*. The number of cells in the battery must be such that at the normal P.D. per cell (2 volts), its total P.D. shall be equal to that between the bus-bars. But if the battery is never required to be connected to the circuit without the booster, the number of cells may be less than this. The exciter is shunt-wound, and a rheostat *R* enables its excitation to be adjusted, in case its pressure should vary owing to the heating-up of the machine after being in use for some hours. The motor is also shunt-wound, and is connected across the bus-bars; its circuit including a starter and regulating resistance, which, however, are omitted from the figure.

The booster armature is connected in series with the battery, so that all the battery current, whether it be on charge or discharge, passes through it. A double-pole throw-over switch *T O S* enables the booster to be cut out, as at night-time, when the battery may be required to deal with the load by itself.

In addition to the shunt-winding mentioned above, the booster has also a series winding *SE*, through which passes a fraction of the main current flowing into the + feeder;

this fraction being determined by the position of the slider on the diverting rheostat *D*, which corresponds with *R* in Fig. 371. The winding *SE* gives a slight boost in the discharge direction, but this is only appreciable when an extra heavy current is flowing to the feeder. Thus its purpose is to assist the discharge when the load becomes very great.

The motor drives the booster and exciter at a constant speed, and the latter gives a constant pressure equal to the normal line pressure. As long as the battery and exciter pressures are equal, there will be no current in *S*, and consequently no boost: but directly the battery pressure falls below that of the exciter, the latter acts as a generator, supplying current through *S* to the battery, and causing the booster to give a pressure exactly equal to the difference between the exciter and battery pressures. The current supplied in this way by the exciter to the battery never exceeds about five amperes, and thus plays no appreciable part in the charging of the battery.

When the battery pressure rises above that of the exciter, a current from the battery will flow through the exciting coil *S* of the booster, reversing its polarity; and also through the exciter *E*, which will now run as a motor. The boost of *B'* will then again be equal to the difference between the exciter and battery pressures, but in the opposite direction.

Suppose the load on the line is a heavy, but decreasing one, and that the battery is on discharge. As the load and the discharge decrease, so causing a corresponding decrease in the drop of volts in the battery, the terminal pressure of the latter rises. If the booster were short-circuited, the bus-bar pressure would rise with the battery

pressure; but with the arrangement above described, the increase in the battery volts decreases the current flowing from the exciter *E* through the shunt-field, *S*, of the booster; thus decreasing the booster-pressure, and tending to maintain a constant pressure on the bus-bars. When the load has so far decreased that the battery pressure has risen to equality with the exciter pressure, the battery is neither charging nor discharging. Then, if the load further decrease, the line pressure rises, since the output (volts P.D. × amperes) of the generators remains the same; and when it has risen slightly above the normal, and so above the battery pressure, a charging current flows through the battery, raising still further the pressure of the latter, so that it now exceeds the exciter pressure. The battery therefore sends a current through the exciter circuit, thus reversing the polarity and consequently the pressure of the booster, which now opposes the battery pressure, and assists the line pressure in charging the battery, thus restoring the former to its normal voltage. It will be seen that the tendency of the arrangement is to maintain a constant pressure on the bus-bars, and in practice it has been found to be more satisfactory than the ordinary motor-booster (§ 181).

A numerical example will complete the explanation. Suppose that the normal bus-bar pressure is 500 volts, and that the battery consists of 240 cells, which are discharging such a current to the bus-bars that the battery pressure has fallen to 480 volts. The pressure required from the booster will then be 20 volts. As the boost always equals the difference between the battery and the exciter pressures (the latter, be it remembered, being the normal

line pressure), the boost obtained will be 20 volts. Should the battery pressure fall to, say, 460 volts, the booster pressure would be 40 volts. Similarly, if the battery be

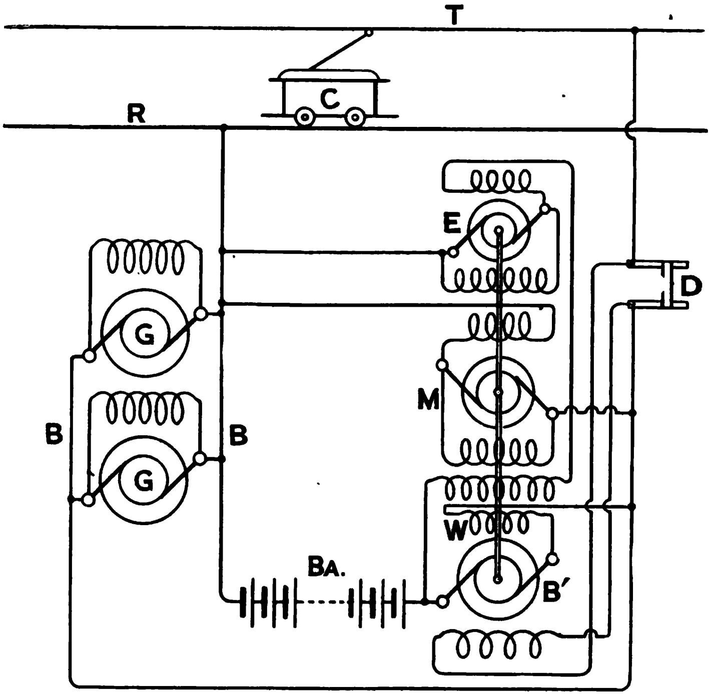


FIG. 373.—The Highfield Reversible Booster as arranged for Traction Work.

charging at a pressure of 550 volts, the boost will be 50 volts in the contrary direction, *i.e.* the difference between the exciter and battery pressures.

The Highfield Booster was primarily designed for use in connection with traction work, such as tramways, where the load is subject to very heavy fluctuations. But it is also eminently suitable for lighting work, and Fig. 372 shows the outers of a set of 3-wire mains joined-up with the bus-bars; the middle wire being connected through a balancer *BAL*, as explained in connection with Fig. 368.

FIG. 373A.—The Highfield Reversible Booster. (Elec. Construction Co.)

Fig. 373 shows the arrangement of the boosting apparatus for traction work. Here *G*, *G* are the generators, *B*, *B* the bus-bars, *BA* the battery, *M* the motor, *E* the exciter, *B'* the booster, and *D* the diverting rheostat. It will be noticed that

in this case *E* is compound-wound, and *M* differentially wound, the speed of the latter being thereby kept more constant. The booster *B′* also has an additional winding, *W*, in series with the armature; the function of this being to compensate for armature reaction. *T* is the trolley wire, *R* the rails, and *C* a car on the line. It should be noted that the – pole of the system is connected to the rails, *i. e.* to earth; this being the usual practice, as the effect of electrolysis is thereby minimized.

Fig. 373A illustrates an actual motor-booster-exciter combination. The motor with its starting-switch and resistance is in the centre, the large machine at the right-hand end of the common shaft being the booster, and the small one at the left-hand end, the exciter.

The field-magnets of a reversible booster must be laminated, in order that—when the magnetizing current in the shunt winding is reversed, on changing over from charge to discharge, or *vice versâ*—the change of polarity may take place rapidly.

228A. THREE-WIRE SYSTEM WITH SINGLE AND DOUBLE DYNAMOS AND SINGLE BOOSTER.—When the 3-wire system was first introduced, *double or twin dynamos* were invariably employed; these being connected between three bus-bars as illustrated in Fig. 359. Then came the multiple bus-bar method (Fig. 363), which enabled some of the dynamos to be shifted from one side of the system to the other, as the load varied on either side. This method was later superseded by the battery regulating systems (Figs. 365—367), in which the middle wire is connected to the battery alone, and only 2-pole generator bus-bars are necessary. The advent of the balancer (Fig. 368), and

of the booster (Fig. 298), still further modified matters; and most direct-current systems now embody either a balancer, balancer-booster, or reversible booster combination, in conjunction with a battery; as per Figs. 369 to 373 and 390.

Fig. 373B represents an arrangement recently introduced at the Rathmines Station, in which, with the object of dispensing with a balancer, twin dynamos are once more used. These are shown at *T D*, and are connected up between the outer bus-bars, *B B*, and the middle bar, *M'*. One, two, or more sets of these double dynamos are

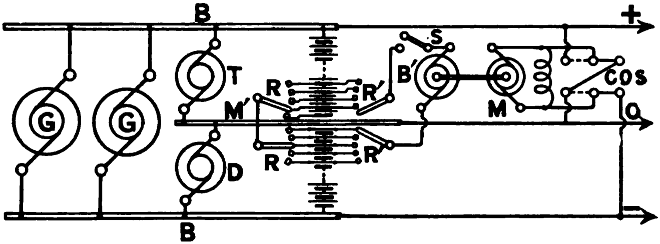


FIG. 373B.—Three-wire System with Single and Double Dynamos and Single Booster.

installed to cope with any possible inequality in the demand; the rest of the generating plant being made up of single generators, *G, G*, which are coupled to the outer bus-bars only.

The battery is permanently connected to the outers, and through regulating switches *R, R* to the middle bar. The advantage of thus placing the regulators on the middle wire, is that the leakage from one set of battery connections to the other, and from both sets to earth, is thereby minimized; as then the P.Ds. between these connections and earth are not more than a few volts.

Other regulating switches R', R' connect a booster B' to the same cells.

By means of R, R the pressures of the two halves of the battery, and consequently also the P.Ds. between the middle and outer mains, may be kept constant. The booster B' is driven by a shunt-wound motor M, the terminals of which may be connected to either side of the system by means of the change-over switch $C O S$. This enables the balancing to be assisted by putting the motor on to that side which is more lightly loaded.

When charging is taking place, the booster is in series with the two sets of cells, its function being to assist the bus-bar pressure in charging the battery. An incidental advantage of the arrangement is that only one booster is necessary, instead of two, as in the ordinary method of charging cells on a 3-wire system (Fig. 390). The field-coils of the generators and booster have been left out in order to simplify the diagram.

The working of the arrangement is as follows. When the battery is charged, the booster is cut out of circuit, and the balance between the two sides of the system is maintained, as will be easily understood, by manipulating the switches R, R. As the cells become discharged, more and more of them are thrown into circuit by means of R, R, to maintain the pressure, until virtually all are in use.

Suppose it be now necessary to charge the cells, the load must first be taken off the batteries by starting-up another generator (or generators), and switching it on to the bus-bars. Then, to commence the charging, the motor M is first started, and the excitation of B' so regulated by means of a rheostat in its field circuit, that the booster voltage is equal to that across the *contacts of* R', R',

so that, before switching-in at *S*, the two pressures are equal. This initial adjustment ensures that the closing of *S* shall produce no disturbance of the potentials throughout the system. The booster is then switched on to the end cells, and its P.D. increased (by strengthening its field) until the required boost is obtained; the E.M.F. of *B′* acting against or cancelling some of that of the battery,

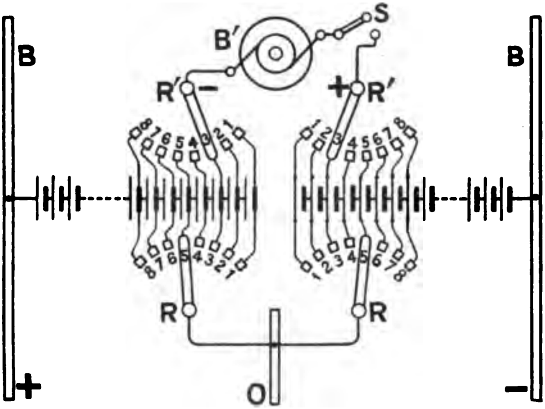


Fig. 373c.—Booster and Regulating Cells.

and thus allowing the constant bus-bar P.D. to send a charging current through the battery.

As the end cells require but little charging, it soon becomes necessary to cut them out one by one by means of *R′*, *R′*; the booster E.M.F. being correspondingly regulated to keep the charging current at its correct value. Balance is maintained by *R*, *R* as before, but it is important that certain relations between the positions of *R*, *R* and *R′*, *R′* be observed. Referring to Fig. 373c, which shows the battery, switches, and booster on a larger scale; it will

be evident that, with R', R' on, say, stops 3, 3, as depicted, if R, R were put on these same contacts, B' would be short-circuited; and would be more so if R', R' were on higher contacts, such as 7, 7, or 8, 8, as the cells would assist. Again if R, R be only a few contacts higher than R', R', the tendency will still be to short-circuit B'. It is necessary that the relative positions of the charge and discharge switches should be such that the E.M.F. of the booster is counter-balanced by the P.D. across the cells in circuit between R and R' on each side. Then there will be no "short-circuit current." If the charging currents through the two sets of cells be unequal, the excess current on the one side will flow through the discharge switch on that side to the neutral wire.

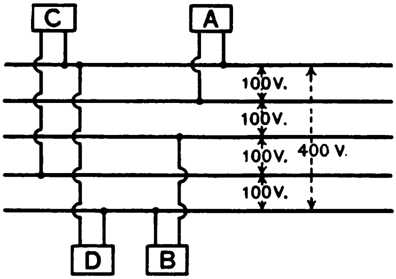


FIG. 374.—The Five-wire System.

229. THE FIVE-WIRE SYSTEM.—In this system the main distributors consist of five conductors; two large outers, and three intermediate cables. The only place in which it is used in this country is at Manchester, where it was introduced in the time of the 100-volt lamp. Now-a-days, when consumers may be supplied at 240 or even 250 volts, the necessity for the system—with its attendant complications—is considerably lessened; 3-wire distribution at present voltages being more economical.

At Manchester, the pressure between the outers is 400 volts, thus giving 100 volts between each pair of adjacent

conductors. For lighting, consumers are supplied at either 100 or 200 volts as at A and B respectively (Fig. 374); and for power purposes at 300 or 400 volts, as at C and D respectively. The 5-wire network is confined to the central part of the city, the remaining area being served from a 3-wire network with 400 volts between the outers. Both networks are fed with direct current. There are three generating stations, two low-pressure ones in the city itself, these feeding direct into the networks; and one high-pressure station on the outskirts, where 3-phase current at 6500 volts is generated. This high-pressure current is "stepped down" in pressure at various sub-stations by means of static transformers, and is then converted into direct current by means of rotary transformers.

To derive the fullest advantage from a 5-wire system, the pressure between the outers might be 1000 volts, so giving 250 volts between adjacent conductors. This, however, would greatly increase the difficulties of insulation.

Five-wire distributors may be supplied from 2-wire feeders, the balance at the feeding points being maintained by means of motor-generators, or batteries, or both; in ways kindred to those diagrammed in Figs. 365 to 370.

230. Summary of Direct-supply Systems.—Nearly all the above-mentioned systems may be described as *direct-supply* ones, to distinguish them from those in which transformers are employed to reduce the pressure at sub-stations, or at feeding points. With the exception of the 2-wire networks, Figs. 349, 351, and 353 to 357, which might be fed, though without advantage, by means of low-pressure alternators; the methods illustrated are clearly only available for use with direct currents. In all direct-

current systems, with or without balancers, if the demand for current be not too great, secondary batteries may be used for supply during light load, these being connected across the bus-bars at the central station, or placed in sub-stations.

Little or nothing has been said about the complete arrangements and connections at the generating station. These naturally are of a most diversified and complicated character, and could not possibly be enlarged upon herein. However, some idea of such may be gathered from §§ 237 to 239, where typical direct- and alternating-current generating systems are described.

The reader who desires fuller information on the matters mentioned in the foregoing and following parts of this chapter, should consult Gay and Yeaman's *Central Station Electricity Supply* (Whittaker), to which work the Author is indebted for much information.

231. TRANSFORMER SYSTEMS OF SUPPLY.—These, as explained in the preceding paragraph, are those systems in which the supply is reduced in pressure on its way from the generating station to the consumers. They may be divided into six classes, according to the character of the current generated, and the character of that supplied to the consumer. Thus:—

CURRENT GENERATED.	CURRENT DELIVERED TO CONSUMER.
(*a*) Direct.	Direct.
(*b*) Monophase.	Direct.
(*c*) Monophase.	Monophase.
(*d*) Polyphase.	Direct.
(*e*) Polyphase.	Monophase.
(*f*) Polyphase.	Polyphase.

The principles of direct- and alternating-current trans-

formers were dealt with in the chapter before this, and it is not necessary to refer to them again. Sometimes the current generated at the central station is "stepped-up" to an extra high pressure before being sent through the mains; in which case it is often "stepped-down" twice before reaching the consumer, once, say, at a sub-station, and once at the feeding points. Such might be the arrangement when the generating station was many miles distant from the city or town supplied.

As explained in §§ 215 and 216, where large areas have to be dealt with, the supply must necessarily be generated at

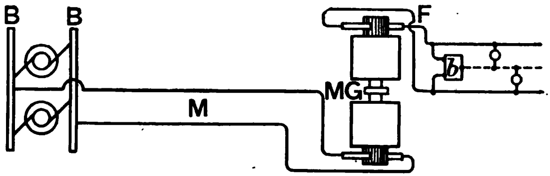


FIG. 375.—Direct-Current Motor-Generator Transforming Station.

high pressure, and generally therefore in the form of alternating current. As regards the consumer, however, it is preferable that the current supplied should be direct, as arc-lighting is then more satisfactory, small motors can be more easily managed, and electrolytic work and the charging of secondary cells are rendered possible without the expense and trouble of a private alternating-to-direct transformer.

232. GENERAL DESCRIPTION OF TRANSFORMER SYSTEMS. —In Fig. 375, *B B* are the bus-bars at the generating station, and to these high-pressure direct-current machines are connected in parallel. From *B B* a number of 2-wire mains, such as *M*, radiate; these terminating at sub-

stations or feeder points, at each of which is placed a motor generator *M G*. The low-pressure side of *M G* may feed into a simple 2-wire distributing network; or into a 3-wire one with a balancer, as at *b*. The pressure on the high-tension mains *M* may be from 1000 to 2000 volts; while with 3-wire distribution, that on the low-tension feeders *F* would be from 400 to 500 volts. This is case (*a*), as tabulated in the foregoing paragraph.

In case (*b*) monophase alternators would feed into *B B*, and *M G* would consist of a single-phase motor coupled to a direct-current generator.

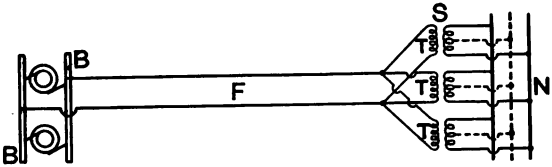


FIG. 376.—Single-phase Static Transforming Station.

Fig. 376 shows the condition of things for case (*c*). Here the generators are single-phase alternators, and the transformers *T*, *T*, *T* are static ones, their secondaries feeding into a 2- or 3-wire network *N*. The latter arrangement is shown in the figure. This transformer system is the one that is at present most extensively used. In practice, a number of pairs of feeders would radiate from the bus-bars *B*, *B*. Instead of one large transformer at the sub-station *S*, it is safer to use a "bank" of two or more connected in parallel, as shown. Then the failure of one would not affect the supply, presuming the others were not overloaded.

(Case *d*.) What may be termed the most modern system

for transmission over long distances, is that in which a high-pressure polyphase current is sent from the distant generating station *G* (Fig. 377) to the sub-station *S*. Here a polyphase motor is coupled to a direct-current generator, which feeds into a 2- or 3-wire network, the latter having a balancer *B*. Or the motor might be coupled, by means of

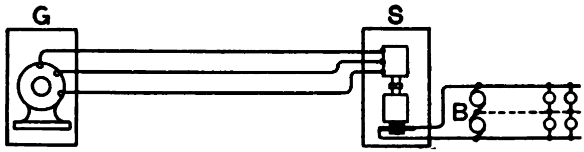


FIG. 377.—Polyphase Motor-Generator Transforming Station.

shafting and belting, to two or more machines feeding into distributor bus-bars; these machines being switched in or out, one by one, according to the demand.

With extra high pressure the polyphase current would be "stepped down" by a static transformer at the sub-station,

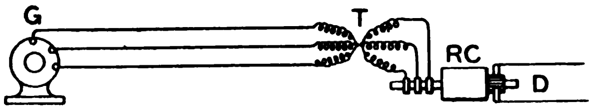


FIG. 378.—Polyphase Static and Rotary-Converter Transforming Station.

and then passed through a *rotary converter*, for transformation into direct current. Such a machine differs from a motor generator, such as is shown in Fig. 335, in that the windings are on a common core. As a matter of fact, as mentioned in §§ 79A and 205, such a machine is identical in construction with the double-current generators described in Chap. XII. The arrangement is illustrated

in Fig. 378, where *G* is the three-phase generator, *T* the transformer, *R C* the rotary converter, and *D* the distributing mains or feeders.

In the exceptional case (*e*), a polyphase motor would drive a single-phase alternator at the sub-station. In case (*f*), either rotary or static transformers could be used.

233. ALTERNATING-CURRENT SYSTEM WITH STREET TRANSFORMERS.—On purely alternating-current systems it is a very common practice to run two sets of mains (high

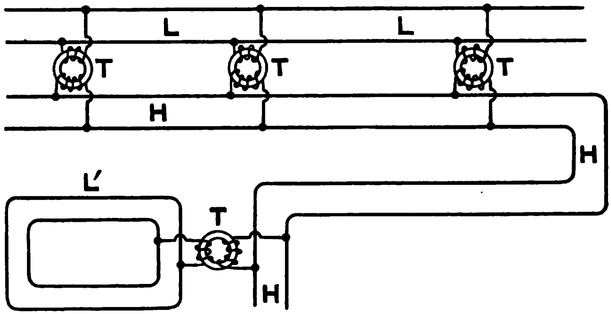


FIG. 379.—Alternating-Current High and Low Tension Mains.

and low pressure) side by side through the principal streets, the low-pressure mains branching off where required down side-streets. The primary or high-pressure mains are supplied from the generating or sub-station (as the case may be) at about 2000 volts; and at various points static transformers are placed in "street boxes" or "street pits," these feeding into the low-tension distributors (or secondary mains) at 240 volts or so.

In Fig. 379, *H*, *H*, *H* are the high-tension mains, *T*, *T*, *T* the transformers, and *L*, *L*, *L′* the low-tension distributors.

The latter would not form one interconnected network when the demand was scattered, but would be put down in independent sections wherever required, as at *L'*. In any given section, as *L L*, additional transformers could be inserted as the demand increased, and the equality of pressure thereby maintained.

On a very large system, the high-tension mains could be supplied from the sub-station *S* (Fig. 376), this in its turn deriving energy from the generating station at a still higher pressure, say 5000 to 10,000 volts.

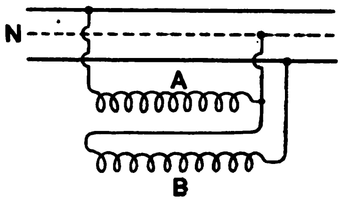


FIG. 380.—Static Balancer.

In certain instances it may be necessary to place transformers in consumers' houses. This is only done in the case of scattered or outlying consumers, as the use of any considerable number of small transformers on a system is not only expensive in the first instance, but also entails a continual extra waste of energy, due to the magnetizing currents taken by the transformers at no load.

When transformers are placed on private premises, care must be taken to guard against the possibility of any dangerous leakage between the primary and secondary. This may be effected by attaching an earthing device to the secondary (Chap. **II.**), or by constructing the transformer with a metallic shield between the two windings, this shield being earth-connected. An objection to the latter method is that there is a risk of fire if an earth fault occur at any point in the house wires; since any accidental

connection between the secondary and the metallic shield would be equivalent to a second fault, and leakage would take place between the two faults thus produced. If, on the other hand, as in the first method, the secondary and the lamp wires attached thereto be more securely insulated from earth, faults must arise at two places therein before serious leakage can take place.

234. THREE-WIRE DISTRIBUTION WITH STATIC TRANSFORMERS.—In Fig. 376 it was shown that 3-wire distributors could be derived from 2-wire step-down transformers at a sub-station or feeder point, by leading conductors away from the middle points of the secondary windings, and connecting these to a neutral wire.

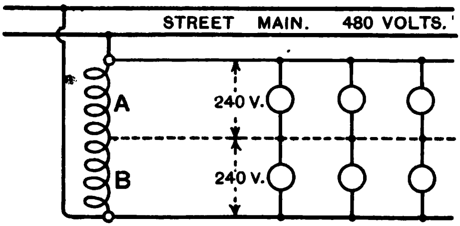


FIG. 381.—Three-wire Transformer.

So-called transformers in which both primary and secondary have an equal number of turns, are useful in maintaining the balance at any point on a 3-wire network. Thus in Fig. 380, N is the part of the network (assumably at some distance from a feeder point), at which it is desired to secure better balance. To effect this, the two windings, A and B, of the transformer are joined together at one end, and connected as shown to the distribution mains. As described on the next page, the supply from 2-wire mains may be utilized for a 3-wire network by using a similar device. Or, on the other hand, a group of lamps

may be run at half or double the voltage that exists on the mains from which the energy is derived.

Such "one to one" transformers, as they are sometimes designated, to denote that the two sets of windings have an equal number of turns, are not transformers in the strict sense of the word, for neither the pressure nor the character of the current is changed.

Fig. 381 shows how a 3-wire distributor can be evolved from a 2-wire or feeder main, without any stepping-down of the voltage. The two windings *A* and *B* are connected

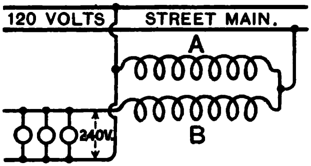


Fig. 382.—Auto-Transformer.

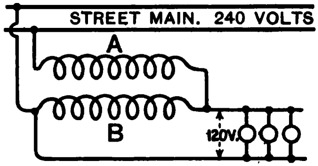


Fig. 383.—Auto-Transformer.

in series across the ends of the feeder, or across the 2-wire mains (as is the case in the figure), and the middle point forms the point of connection of the neutral wire. Used in the fashion, or for the purpose shown in Fig. 380, the device is conveniently termed a *compensating or balancing coil*, or a *static balancer.* It will keep the pressure on each side quite equal, in spite of great inequalities of load. The arrangement seen in Fig. 383 is merely an extension of that depicted in Fig. 381.

When connected as in Fig. 382, the apparatus becomes an *auto-transformer*, the coil *A* acting inductively on *B*, and inducing a pressure therein equal to its own. This induced pressure is added to that already on the

circuit, so that the consumer's supply pressure is double that on the mains. On the other hand, by connecting the coils as in Fig. 383, the consumer's pressure is reduced to half that on the mains. In this case, as *A* and *B* are in series across the mains, the P.D. at the terminals of either is half that of the mains; both the coils acting as "chokers" when the consumer's circuits are open. When lamps, etc., are "on," a portion of the current flowing through them is derived directly from the mains, and the remainder from *B*, on which *A* acts inductively. This arrangement is thus

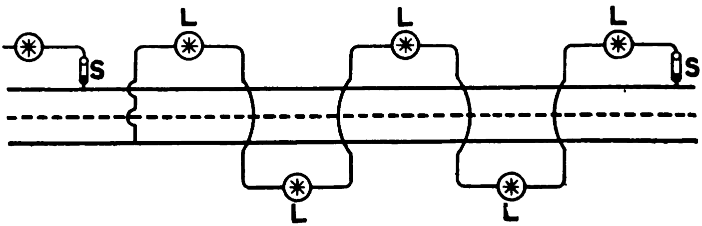


FIG. 384.—Street Arc Lamp Circuit.

in the nature of a choker and auto-transformer combined. The action of these devices, which, by the way, are only used as adjuncts to an alternating system of supply, is also referred to in Chap. I.

235. STREET LIGHTING.—The lighting of main streets is usually effected by means of arc lamps, and that of by-streets with glow lamps. The latter are connected in parallel across the distribution mains, and no special arrangements are necessary. With arc lamps, on the other hand, there are many different ways of laying out the circuits, the more modern of which will now be described.

The most simple way of connecting the arc lamps is to join them up in series groups across the outers of the street distribution mains, as illustrated in Fig. 384, which shows one group of five lamps *L*, *L*, etc., and the first lamp of a neighbouring group. The number of lamps that can be put in any one group depends firstly on the pressure between the mains, secondly on the character of the current (direct or alternating), and lastly on whether the lamps are of the enclosed or open type (Chap. I.). Such groups are switched on and off by means of switches *S*, *S*, necessitating the perambulation of the district by a lamp-

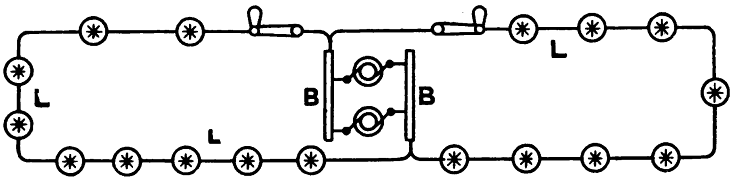


FIG. 385.—Street Arc Lamp Circuits.

switcher. It is possible, however, to arrange for the operation of these switches by special apparatus controlled from the central station.[1]

Another way (Fig. 385) is to run the circuits straight from the bus-bars in the generating station, this giving direct control over the lamps. When the generating system is a high-tension one with 2000 volts or so between the buses, each circuit may comprise a large number of lamps. In the figure, *B*, *B* are the station bus-bars, and *L*, *L*, *L* the lamps, two circuits being shown. Such circuits may also be connected up to the bus-bars in sub-stations,

[1] As in the "Selector System," for example.

and operated therefrom; this being more frequently the case, as the sub-stations are of course usually nearer to the centres of demand than the generating station. In the case of a direct-current system, the current through the lamps is regulated by a suitable adjustable resistance. With alternating currents, a choking coil (§ 50) is employed to the same end.

When the system is an alternating-current one, and

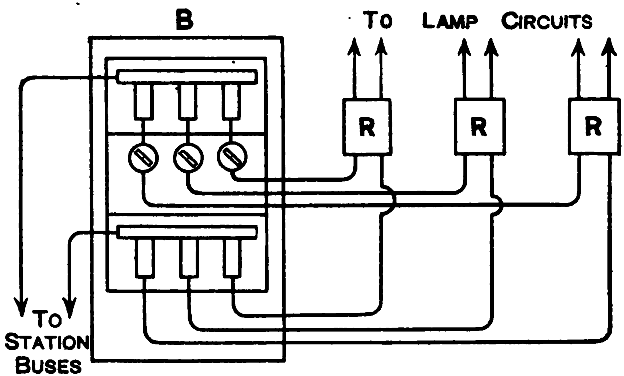


FIG. 386.—Connection of Arc Lamp Circuits to Ferranti Rectifiers.

alternating-current lamps are objected to, the current supply may be made unidirectional by means of Ferranti rectifiers, a description of which was given in § 207. Fig. 386 shows the disposition of the circuits, etc. The rectifiers *R*, *R*, *R* are connected in parallel to a distribution box *B* (containing switches and fuses); this, in its turn, being connected with the station bus-bars. Each rectifier supplies its own series group of lamps.

When alternating-current lamps are used, they may be

inserted in the secondary circuit of step-down transformers connected across either the distributing or the feeder mains. In the first case, it is usual to run only one or two lamps in each circuit, as in Fig. 387; while in the second, a group of lamps may be connected either in series or in parallel to the transformer, as at *A* and *B* respectively in Fig. 388.

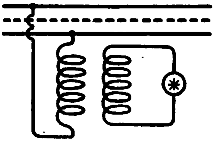


FIG. 387.—Street Arc Lamp Circuit.

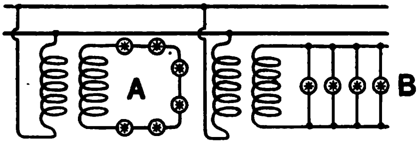


FIG. 388.—Street Arc Lamp Circuits.

The last system to be illustrated is that in which a pair of high-pressure mains is led round the district, and each lamp derives its supply from a separate transformer connected across the mains, as depicted in Fig. 389.

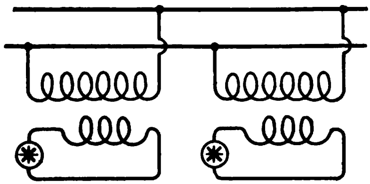


FIG. 389.—Street Arc Lamp Circuits.

236. SUPPLY OF POWER FOR TRAMWAY AND RAILWAY WORKING.—Power for electric tramway working is usually generated by plant quite separate from that which supplies current for the lighting of a town, the feeding and distribution mains also being quite distinct. One reason for this is that the earthed "return" of a tramway system could not, in most cases, be included in a lighting system.

The feeder mains for a tramway system would have to be separate even if it were considered preferable to derive

the supply from the lighting generators; otherwise the large and sudden fluctuations of load on the tramway circuit would cause corresponding and serious fluctuations in pressure at the lamps. The greater the number of cars in operation, however, the less are the percentage fluctuations in the load. Still, with even a large number of cars running, there may be sudden jumps in the demand of several hundreds of amperes. In other words, loads amounting to as much as 100 or 200 horse-power are thrown on or off the generating plant without a moment's notice. Hence generators for traction purposes, and the engines that drive them, have to be specially strongly built to enable them to withstand such sudden strains. The latter however may be minimized by the use of storage batteries to cope with the heavy demand; these providing a steady and economical load for the generators, and reducing the necessity for stand-by plant. The Highfield reversible booster (§ 228) was primarily designed for traction stations.

The methods of running electric trams were described in § 129, and it was there mentioned that the battery-car system had too many drawbacks to permit of its use. So great are these drawbacks, that they outweigh the obvious advantages attending the absence of a feeding and distributing network, and of overhead or underground contact gear.

Referring to the other systems mentioned in § 129, whether the conductor with which the cars make sliding or rolling contact be placed overhead or underground, the feeder system may be the same. In all cases direct current is used, and the usual working pressure is 500

volts; but there are numerous ways in which the generating and distributing systems may be arranged.

When the generating station is near the line, the supply may be taken direct (*i. e.* without transforming down) through a number of feeders to various points along the lines of route, these feeders charging the trolley or underground conductors, as the case may be. When the generating station is some distance away, the energy is generated at high pressure, and transformed down at sub-stations. When this latter system is adopted, polyphase generators may be employed, and polyphase-to-direct-current rotary transformers connected at the ends of the high-tension feeders. From each sub-station, one or more low-tension feeders would run to the trolley or underground conductors. The current, after it has passed through the motors, and on to the rails, travels through earthed return cables back to the sub-stations.

In electric railway work the arrangements are much the same, except that in place of the trolley or underground wire, an insulated conductor of copper or steel (called the third rail) is placed between, or at the side of, the rails on which the trains run; the latter taking current from this rail by means of a sliding contact. Here again the usual working pressure is 500 volts.

237. TYPICAL DIRECT-CURRENT STATION.—It will be evident from the foregoing, that in the drawing up of any scheme for electricity generation and distribution for a given town or district, the engineer has the choice of numerous different systems. And any given outline system may be modified, as regards details, in a great number of different ways. In fact there is hardly such a thing as a

standard system. Owing to the great variety of switching and regulating gear, and of measuring instruments, the main switchboard for any given system may also be arranged in very many ways. It must suffice then if we give diagrams showing the principal connections in typical low-tension direct- and single- and polyphase-current stations respectively, the latter being dealt with in the two next paragraphs.

Fig. 390 gives a diagram of the chief switchboard and other connections in a direct-current generating station feeding direct (*i.e.* without transforming) into a 3-wire network; a secondary battery with balancers and boosters forming part of the system. The diagram, which is at first sight a little complicated, should be studied carefully, when its details will become clearer. To prevent it being too involved, no voltmeter connections are shown. In reality there would be almost as many voltmeters as ammeters: some to show the P.D. at the generator, balancer, and booster terminals; others to indicate the pressure between the + and − bars, or between each outer and the middle bus-bar, as well as the battery pressure, or the *difference* between the battery and the bus-bar pressures; and yet others connected by pilot wires with the far ends of each pair of feeders.

Dy, Dy are two of the dynamos, and *F, F* their field coils, the latter being connected through rheostats *R, R* with their respective dynamo terminals. *R, R* enable the excitation of the dynamos, and consequently their terminal P.D., to be varied at will, as described in § 11. The leads from the generators pass on either side to the vertical bars, *D, D, D′, D′*, on the plug switchboard; reverse-

current cut-outs, *R C C*, and main switches *M S*, being included in the leads on one side; and ammeters *A*, and fuses *F* on the other. *A* in either case indicates the current taken from its machine, and *F* prevents too much being drawn from it. On the other hand, should the P.D. of a dynamo fall below that on the bus-bars, current will tend to run back through it; but before this can occur, *R C C* opens the circuit. The construction and action of a reverse-current cut-out was fully described in Chap. **II.** Any number of dynamos would be connected in like manner, each extra machine installed being joined up to its own pair of bars.

Side by side with these dynamo bars are the feeder bars $F_1 F_1$, $F_2 F_2$, $F_3 F_3$, the ends of the feeders being connected thereto through fuses *F* and ammeters *A′*. F_1 F_1 are one pair of feeders, F_2 F_2 another pair, and so on. Spare dynamo and feeder bars would be mounted on the switch-board to provide for extensions. Duplex fuses and a change-over (or two-way) switch are inserted in each feeder, so that should a fuse blow, the supply is only momentarily interrupted. Thus, referring to the + feeders, on the right-hand side of the figure, if fuse *f* gave way the two-way switch *T W S* would immediately be put over so as to throw the spare fuse *f′* in circuit, a new fuse being then fitted at *f*. Instead of these fuses, excess-current circuit-breakers (or magnetic cut-outs) are more convenient, as, being usually in the form of a switch, they can easily and quickly be replaced in the "on" position. They are much more expensive than fuses however. Some forms of these are illustrated in Chap. **II.**

The *middle-wire* cables of the system are connected to

the middle wire bar *M W B*; and the latter, through an ammeter *A*, is connected with the centre of the secondary battery *S B*, and *vid M W C* (middle wire conductor) with the rheostats *R*, *R*, and *S R*, the functions of which will be described presently.

For the purpose of supplying the balancing current required on one side or the other of the system, and so keeping the pressures equal; and for helping to charge the cells by adding to the dynamo E.M.F., or for adding E.M.F. to the cells when the latter are discharging, the combined *balancer and booster set* denoted by *BS*, *B L*, *B L*, *BS* is employed. This machine consists virtually of four dynamos coupled together; the two inner ones *B L*, *B L* acting as a balancer, and the end ones *B S*, *B S* as boosters, the latter being driven by the former as the four armatures are mounted on the same shaft. An actual machine of this description is illustrated in Fig. 337, and such is generally termed a *balancer-booster*. The diagram shows only the commutators and field coils of the various machines, the coils being drawn at the side of each commutator. The fact that the machines are rigidly connected together is denoted by the double dotted line, which may be taken to represent the shaft.

The main balancer circuit is denoted by the lines *B*, *B*, *B*, *B*. At each side it terminates (through an ammeter *A*) in a lower horizontal bar, these being generally at the back of the switch-board slate, and therefore shown dotted. To these bars are also connected the + and — ends of the battery respectively, *vid* the battery-regulating switches *B R S*, *B R S*, ammeters *A*, *A*, and two-way switches *T*, *T*. The battery-regulating switches enable

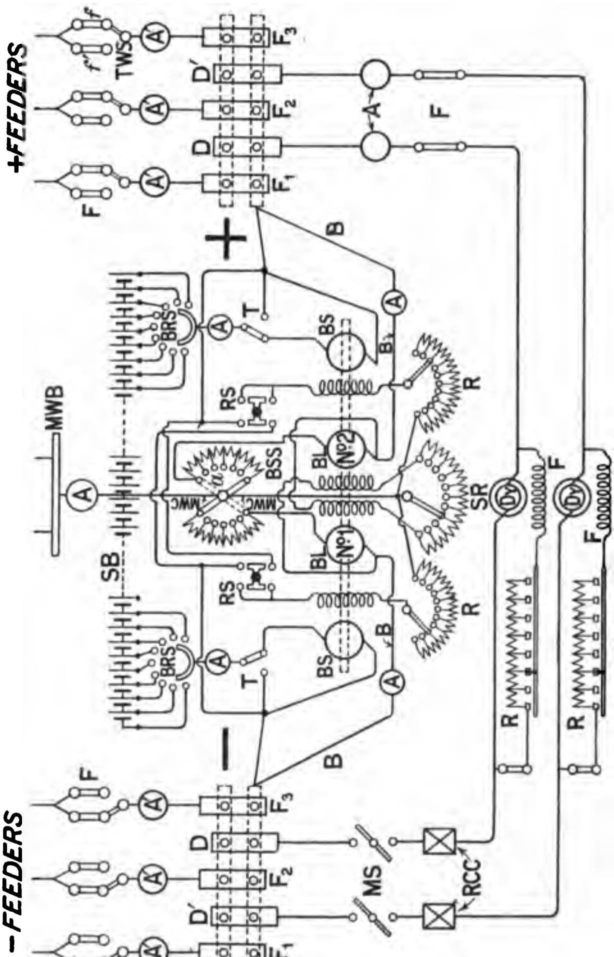


FIG. 390.—Direct-Current Station Connections.

the number of cells in circuit on either side of the middle wire to be altered at will.

Besides the battery and balancer bar, there is a second horizontal bar on each side; and either of these may be connected by means of plugs (similar to that in Fig. 364) with any of the vertical feeder or dynamo bars as required. This arrangement of bars enables the feeders to be connected to the dynamos alone, to the battery alone, or to both; the latter being the normal state of things. Or some of the feeders may be connected to, say, one dynamo alone, and some to the battery and the other dynamo. Or while one dynamo is supplying all the feeders, the other may be charging the battery.

Between the two balancer armatures is connected the balancer starting switch *B S S*, which, in the firm line or starting position, puts in all its resistance between the two sides of the balancer circuit and their point of connection with *M W C* at the centre of the switch. In starting-up the balancer, the resistance is gradually switched out, and when the arm reaches the dotted position *a* there is none at all in circuit. Presuming the loads on the two sides are equal, the balancer runs as two motors in series. The balancer exciting coils are connected in series across the outer bus-bars, through a stepped resistance *S R*, the contact arm of which is joined up to the end of *M W C*. The field coils of armature No. 1 are in shunt to the armature No. 2, and those of armature No. 2 in shunt to armature No. 1.

As before stated, when balance exists between the two sides of the system, each balancer armature runs as a motor, and their combined work consists merely in

driving the boosters at each end of the common shaft. Suppose now the positive side become more heavily loaded than the negative side, the P. D. on the positive side will drop below that on the negative side. Then the field excitation and hence the back E.M.F. of the negative balancer armature, which is energised off the positive side, will be decreased: the current taken by the armature will therefore increase, and the machine will act as a motor, driving not only the boosters but also the positive balancer armature, which will then act as a generator and supply the extra demand on that side.

In the case of long feeders, this automatic balancing is often insufficient to keep the pressures at their far ends equal; and it is on this account that the stepped resistance or rheostat *S R* is employed. If, for example, the increase in load occur on the positive side, the switch arm is moved to the right, thus taking resistance out of the generator field circuit of the balancer and putting it in that of the motor. The effect of this is to cause the P. D. at the station between the feeder and middle wire on the + side to be greater than that on the − side, so compensating for the extra drop on the + feeders.

We have lastly to consider the functions of the two boosters. First of all, it should be noted that one end of the field coil of each is connected through a rheostat *R* with *M W C*; and the other end with a reversing switch *R S*, the poles of which are connected with the + and − bus-bars. It is evident, therefore, that by means of *R S*, the polarity of either booster may be reversed at will. One end of each booster armature is permanently connected with its respective bus-bar, and the other to one of the

contacts of the two-way switch *T*, by means of which the booster may be inserted between the bus-bar and the end of the battery, or cut out altogether. The diagram shows the boosters in circuit.

In charging the battery, the E.M.F. of the boosters is in such a direction as to boost-up or increase the P.D. across the cells due to the generators. On the other hand, when the battery is discharging, the E.M.F. of the boosters is reversed by means of *R S*, *R S*; and they are then enabled to boost-up or assist the battery E.M.F.

As already stated, the above is but one of numerous ways of arranging the connections of a direct-current station, and it may be modified in a number of ways. It is a good representative method however for a small station. In a very up-to-date system, an automatic reversible booster would preferably be used (§§ 227, 228).

238. SINGLE-PHASE GENERATING AND SUB-STATION CONNECTIONS.—Here we have a great number of arrangements at disposal, though perhaps not so many as in direct-current work. In the following figures (391 to 395) the connections have been simplified as much as possible, and various regulating and indicating apparatus, that would be necessary in actual work, have been left out of account.

In Fig. 391, *A L* is a single-phase alternator feeding through the fuse *F*, switch *S*, and ammeter *A* into the bus-bars *B*, *B*; the pressure on which is indicated by the bus-bar voltmeter *B B V*. *E* is the exciter (a small direct-current generator) supplying the magnetizing current to the field-windings *F W* of *A L*, *f* being the exciter field-coil, and *R* a rheostat in circuit therewith. Generally, of

course, there would be a number of generators feeding in parallel into the buses; and arrangements would then have to be made for synchronizing them, as illustrated and described in § 78, and as further illustrated in Fig. 392.

F′, *F′* are pairs of feeder-mains, with ammeters *A*, *A*, in

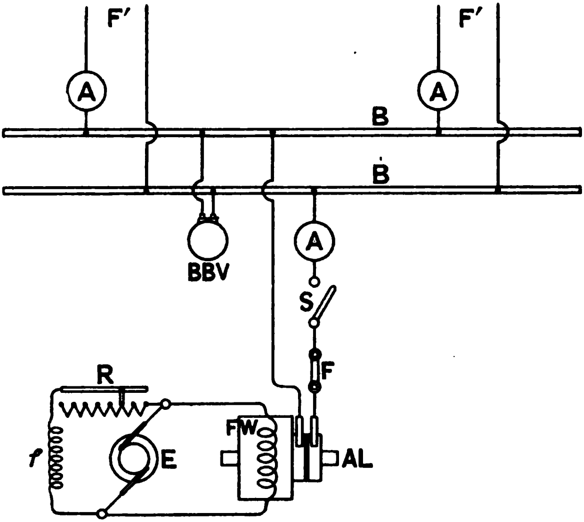


Fig. 391.—Simple Alternating-Current Station.

one side of each pair. Some methods of regulating the pressure on such feeders were illustrated in Figs. 325, 326, and 328.

Fig. 392 shows a more complete arrangement. Here *A L* and *A L′* are single-phase alternators, the complete connections of the former only being indicated. The exciting-current for each alternator is derived either from a direct-

current exciter *D*, or from exciter bus-bars *E B*, to which a secondary battery *S B* is connected. The office of this

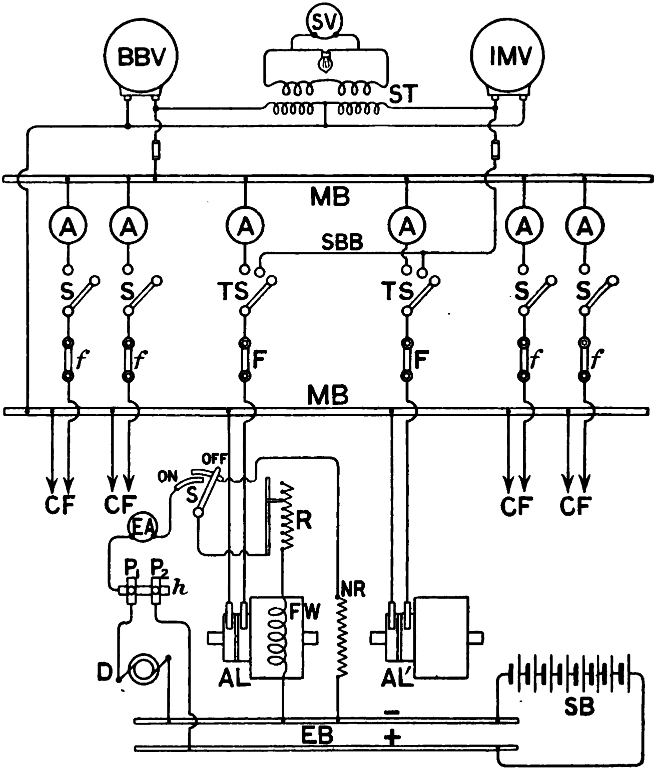


FIG. 392.—Single-phase Generating Station.

battery is to provide current for the field-windings in case of any of the exciters breaking down, or having to be

stopped. One end of the alternator field-winding *F W* is permanently joined-up to, say, the – bar of *E B*; and the other, *viâ* a rheostat *R*, to the 2-way switch *S*; which, in the "off" position indicated, short-circuits *F W* and *R* through the non-inductive resistance *N R*. It should be observed that in moving the switch from the *on* to the *off* position, and so throwing *N R* into series with *F W*, the circuit of the latter is never broken. If the field-winding circuit were simply broken, or were broken during the passage of the switch from one position to the other, great strain would be thrown on its insulation, owing to the high E.M.F. that would be induced. The arrangement shown effectually prevents this. A special switch for this and similar purposes was described in § 39.

One pole of the exciter is joined up to the same bus-bar as the end of the alternator field (in this case to the – bus), and the other pole to a plug-bar P_1. The positive bus-bar is connected to a neighbouring plug-bar P_2. When P_1 is plugged on to the horizontal bar *h*, and *S* is put "on," *D* furnishes the exciting current, the strength of which is indicated by the ammeter *E A*. If *D* break down, the battery may be brought into use by plugging-in P_2. With *S* "off," and both P_1 and P_2 plugged in, *D* is connected for charging the battery. The field-circuit of *D* is omitted from the figure.

M B, *M B*, are the main buses. One pole of each alternator is connected straight to the lower bar; and the other to the upper bar, through the fuse *F*, 2-way switch *T S*, and ammeter *A*. The figure shows the switch of each alternator in the "off" position. When either switch is moved on to its first contact, the machine is connected through the

synchronizing bus-bar *S B B*, with the "incoming machine voltmeter" *I M V*, and the synchronizing transformer *S T*. As the pressure of the "incoming machine" rises, so also will the indications on *I M V*. As was explained in § 78, if the frequency (*i.e.* the speed) of the incoming machine be not correct, the lamp shunting *S V* (the synchronizing voltmeter) will light up and go out at rapid intervals. The speed must then be adjusted until the light of the lamp rises and falls only a few times a minute; and the machine is switched on to the bars at the moment the lamp is at full incandescence, and the indication on *S V* corresponds with that on *B B V*; *T S* being put over to its second contact, thereby connecting the alternator to the upper bar through the ammeter *A*.

C F are concentric feeder cables connected straight to the one bar; and through fuses *f*, switches *S*, and ammeters *A*, to the other bar.

The arrangement of transformers and switch-gear in the sub-stations is depicted in Fig. 393. Here *H T B* are high tension bus-bars, to which the ends of the feeders *F*, *F*, coming from the generating station, are connected through double-pole fuses *D P F*, *D P F*. The pressure on *H T B* is indicated by the voltmeter *H T V*, which is connected through the small step-down transformer *T'*. *T*, *T* are the main step-down transformers which convert the high-tension current, derived from *H T B*, into low-tension current, which is delivered to the low-tension buses *L T B*. The primaries and secondaries of these transformers are connected to their respective bus-bars through D.P. switches and fuses, the secondaries being provided with voltmeters and ammeters as shown. The

pressure on *L T B* is indicated by a voltmeter *L T V*. *L T F*, *L T F* are the low-tension feeding or distributing cables (as

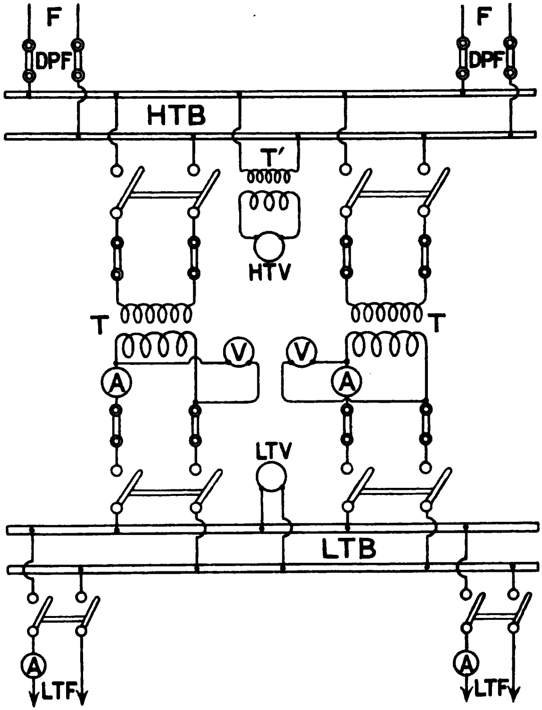


FIG. 393.—Single-phase Sub-station with Static Transformers.

the case may be) supplying the distribution network; and each of these is connected to *L T B* through an ammeter and D.P. switch.

239. THREE-PHASE GENERATING AND SUB-STATION

CONNECTIONS. Fig. 394 is a simplified diagram of the connections at a polyphase-current generating station. *T P G*, *T P G* are two three-phase generators joined-up through excess-current oil-break automatic circuit-breakers *E C B*, *E C B*, ammeters *A*, *A*, *A*, and triple-pole switches *T P S*, *T P S* with the bus-bars *B B*. These main bars supply the triple-conductor feeders *F*, *F*, leading to the sub-stations (Fig. 395), through other excess-current circuit-breakers *E C B′*, *E C B′*, and reactance or choking coils *R C*, *R C*, whereby the pressures on the feeders may be adjusted. The pressure on the bus-bars is indicated by the voltmeter *V*, which is joined-up across the secondary of a small step-down transformer, it being only necessary to connect this voltmeter to two of the bars. The synchronizing gear, which is somewhat complicated in 3-phase working, has been omitted for the sake of simplicity.

The generators are supplied with magnetizing current from exciter bus-bars *E B B*, the current being taken in each case through a D.P. switch, rheostat, and ammeter to the brushes and slip-rings, when, as shown in the figure, the generators have rotating field-magnets. *N R*, *N R* are non-inductive resistances which are thrown in series with the field-circuit at the moment of switching off the exciting current, for the same purpose as was explained in connection with Fig. 392. (See also § 39.)

The exciter bus-bars *E B B*, are fed by one or more continuous current generators or exciters *E*, *E*; the current from each of which is led through an ammeter *A* and double-pole switch *D P S* to the bus-bars. Regulation of the voltage at the terminals of the exciter is effected by varying the excitation by means of the

rheostat *R*. When the bus-bars *E B B* are already "alive" and an extra exciter is to be switched on to them, the

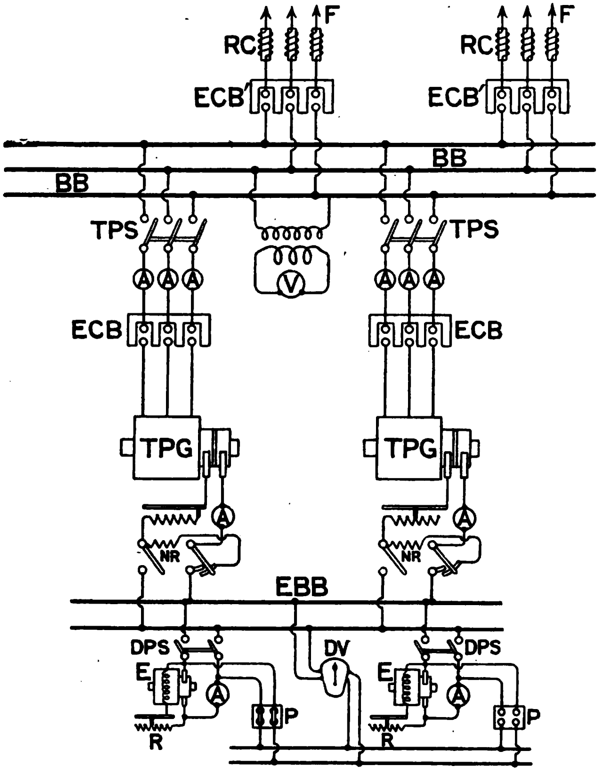


FIG. 394.—Polyphase Generating Station.

terminal voltage of the exciter must first be adjusted to the same value as the voltage on the bus-bars. When

this equality is obtained, the differential voltmeter, *D V*, which is provided with a central zero, will indicate no volts, and the switch *D P S* may then be closed. When the two voltages are unequal, the needle will be deflected to one side or the other according as the bus-bar or the exciter voltage is the greater. The potential plugs *P*, *P*, enable one differential voltmeter to be used for two or more exciters; the instrument being connected to any one exciter by inserting its respective plug, which bridges across the gaps as shown at the left-hand plug in the figure. The right-hand exciter is unplugged.

A sub-station in which the 3-phase supply received from the generating station is converted into direct current by means of motor-generators, is depicted diagrammatically in Fig. 395. The high-tension 3-phase current enters the station by one or more triple-conductor cables *T C C*, and is delivered through a triple-pole switch *T P S* and ammeters, *A*, *A*, *A*, to the high-tension buses *H T B*. Its pressure is indicated on the voltmeter *V* through a small step-down transformer, it being sufficient, as already explained, to connect this to two wires only. The spark-gaps *S G* enable any dangerously high pressure, which may be developed owing to the capacity effect (§ 55) of the cables, to dissipate itself by sparking across. The pressure on *H T B* is indicated by a voltmeter V_1 which like *V*, is preferably connected through a small step-down transformer; these instruments being calibrated accordingly.

P M, *P M* are polyphase motors connected with *H T B* through triple-pole switches and fuses; *S R*, *S R* being their starting resistances, the function of which was explained in § 140. In the figure, each motor is shown

as driving two direct-current dynamos *D, D*; the field-

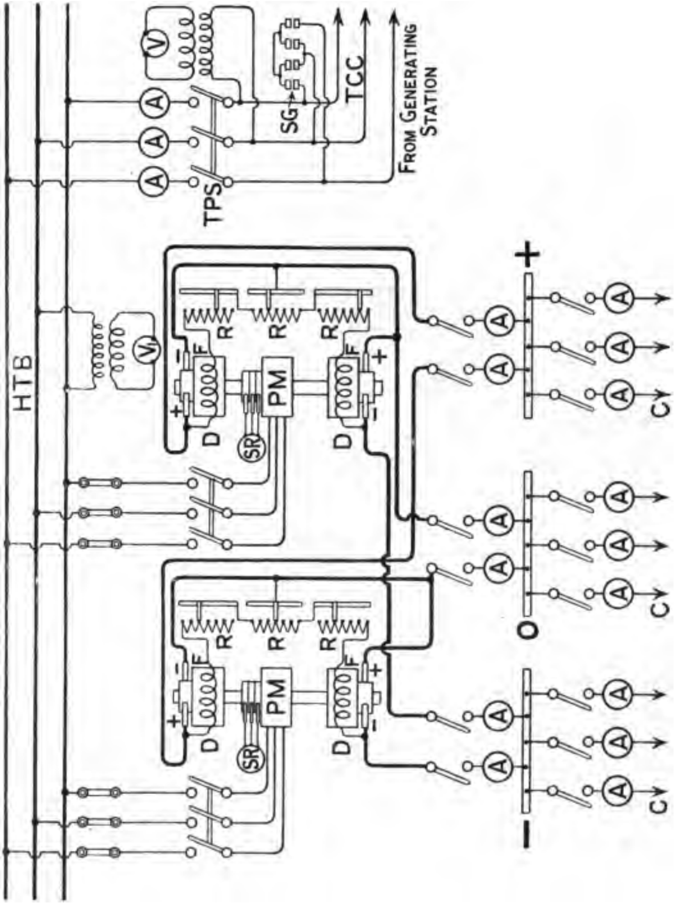


FIG. 395.—Polyphase Sub-station Transforming to Direct Current.

coils *F F* of which are shunt-wound, and connected in a

special way to the rheostats *R*, *R*, *R*. The main circuits of the dynamos are indicated by the thick lines. These pairs of machines feed into low-tension 3-wire bus-bars –, 0, +, in an exactly similar manner to that shown in Fig. 395; and to these buses the +, neutral, and – feeding or distributing cables *C*, *C*, *C* are connected. Balance between the two sides of the 3-wire system is maintained by the help of the rheostats *R*, *R*, *R*. If each motor drive a single dynamo only, the P.D. of which is equal to that

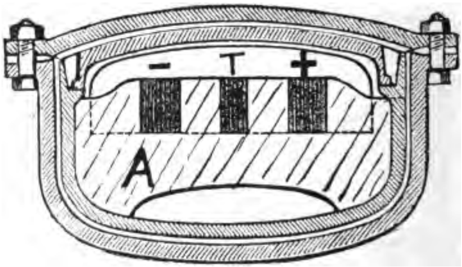


FIG. 396.—Bare Mains.

between the outers; balance may be maintained in any of the ways already described (Figs. 368, 369, etc.).

240. OVERHEAD AND UNDERGROUND MAINS; BARE COPPER MAINS.—In the earliest days of electric lighting, the current was conveyed from point to point by means of bare or covered wires mounted on insulators and poles overhead; in much the same manner as some telephone and telegraph wires are run at the present time. Now-a-days, except in very special cases, or in villages and outlying districts, the conductors are put underground.

In some places, bare copper conductors mounted on

insulators in cast-iron pipes or conduits are still used. An illustration of one of various such systems is given in Fig. 396. The conductors have no insulating covering whatever, and are made up of strips of copper laid side by side in cast-iron troughs. These are insulated from the troughs and are supported by arch-shaped stoneware insulators, placed at intervals, and having three notches formed in the top to receive the copper strips composing the three conductors. *A* is one of the insulating stoneware blocks, and +, *T*, and −, the positive, neutral, and negative mains respectively. One advantage claimed for this system is that extra copper strips can easily be put in place as the demand for current increases, without disturbing the rest. Another is that there is no insulating covering to pay for and to depreciate. On the other hand, there is serious risk of breakdown through flooding of the conduit.

Where it is desired to lead the current into a consumer's premises, a hole is drilled through the side of the iron trough, and a piece of gas-pipe tapped into it. The consumer's service wires, which are of ordinary insulated cable, are led through this pipe, their connection with the copper strips being a very simple matter.

Such a system of bare conductors is only advisable on a low-pressure or 100-volt supply, as the surfaces of the insulators are always to a certain degree dirty and damp, so that with high pressures considerable leakage would take place between the mains, to say nothing of electrolytic action.

Systems of this class, which were rather extensively used at one time, are dropping out of favour now that high-pressure supply is the order of the day.

241. METHODS OF LAYING MAINS.—Modern systems of laying mains may be classified as either *draw-in* or *solid.* In the former the cables are drawn through pipes or conduits, and can be withdrawn and replaced by fresh ones at any time. In the solid system, the conductors are virtually buried in the ground; and the soil has to be opened up whenever it is desired to get at the cables.

In draw-in systems, the pipes are of cast-iron or steel, or sometimes of stoneware. Besides pipes, blocks of

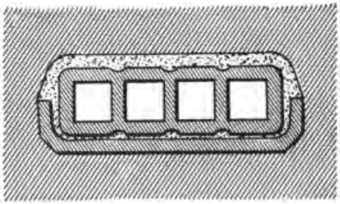


FIG. 397.—Four-way Doulton Conduit.

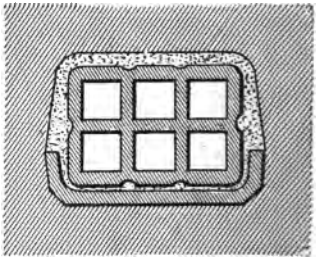


FIG. 398.—Six-way Doulton Conduit.

stoneware, cement, bitumenized wood, or other semi-insulating material are also used. These blocks have a number of ducts or cable-ways passing through them, and are placed end-to-end in the trench with water-tight jointing. Figs. 397 and 398 give sections of 4-way and 6-way Doulton stoneware conduits.

Solid systems are of two kinds. In the first, the cables are laid in wooden or stoneware or iron troughs, which are then filled in with pitch or similar insulating compound, a cover put over, and the trench filled in. In the second solid system, the cables, which must of necessity be

armoured in this case, are laid straight in the trench, with perhaps simply a boarding over them to warn future excavators of their presence.

An example of the first method is illustrated in Fig. 399, which gives a section of a stoneware trough in which the cable is embedded in bitumen, the top being then filled in with cement. In Fig. 400 are given three forms of stoneware trough with stoneware covers, the cables being "run in" with bitumen or other insulating "compound." The lower trough, it will be observed, carries the three cables of a 3-wire system. In the Howard system, the troughing is made of asphalt with an outer lining of thin sheet-iron. The cables are laid in the trough and then "run in" with bitumen, the top being filled in with asphaltic concrete. Fig. 401 shows a trough of this kind with the three cables of a 3-wire system *in situ*.

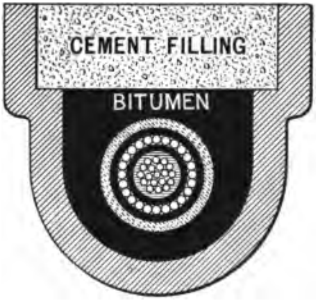


FIG. 399.—Sykes Cable Trough. (Albion Clay Co.)

In addition to that at the feeder points, means of access to the cables are provided at numerous places on the distributing network; these being generally in the form of connecting and draw-in manholes, and pits or boxes, which are additional to the service boxes already referred to (§ 219).

242. TYPES OF CABLE.—As regards their conductors, cables may be classified as *single-*, *double-*, or *triple-core*,

according to the number of separate conductors comprised in the cable. When there are more than three conductors, cables become *four-core, five-core, six-core,* and so on, as the case may be. The upper left-hand and lower illustrations in Fig. 400 show single-core cables, while double-core

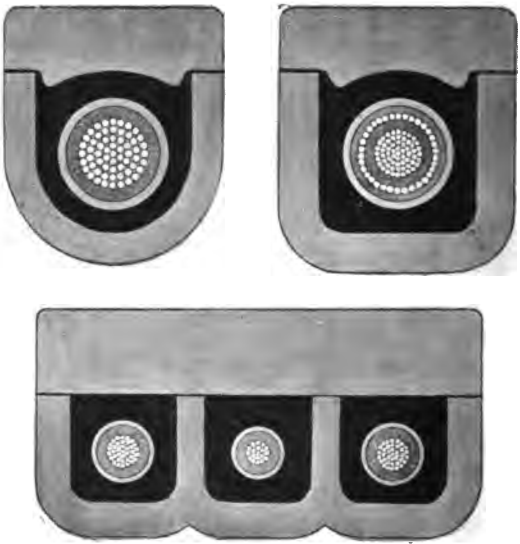


FIG. 400.—Doulton Troughing.

ones are to be seen in Fig. 399, and in the upper right-hand illustration of Fig. 400. Figs. 403, 405, and 407 are triple-core, and Fig. 402 four-core; while Fig. 404 is a six-core cable, this being a three-wire feeder with pilot wires. Ordinary *concentric cables* are double-core ones, in which one conductor surrounds the other, as in Fig. 399.

A *triple concentric cable* has three cylindrical conductors, one within the other. Figs. 403 and 405 are *twin concentric* cables, and are suitable for polyphase work. Fig. 402 is for three-phase working with a balancing wire; and Fig. 406 is a three-phase cable with an earth sheath as prescribed by the Board of Trade.

As regards their insulation cables are either ordinary or *hygroscopic.* Those with hygroscopic insulation must of

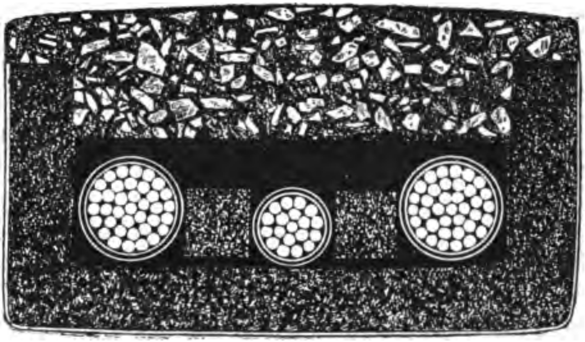
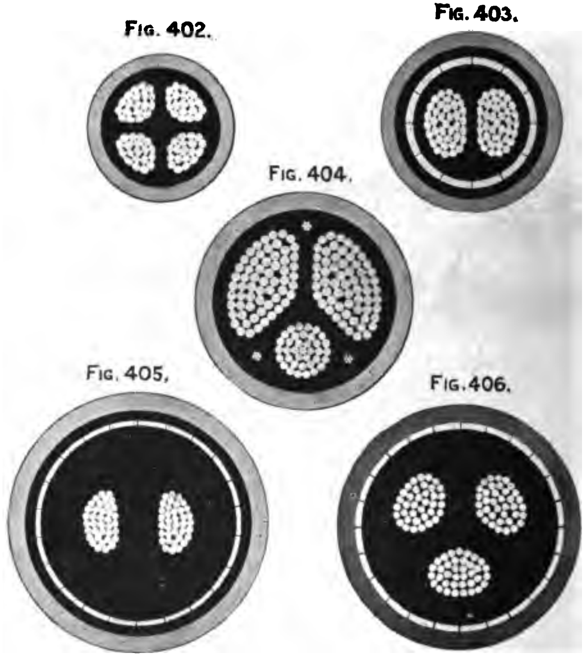


Fig. 401.—Howard Trough.

necessity have a sheathing of lead, and are thus termed *lead-sheathed cables.* Examples of such are given in Figs. 402 to 407. *Armoured cables* have an outer sheathing of lead, or of steel or iron wire or tape, in the case of ordinary cables; and of steel or iron wire or tape, in addition to the lead sheathing, in the case of hygroscopic ones. Fig. 407 is a section of a lead-sheathed wire-armoured cable.

Possibly the best, and at the same time the most expensive insulation, is vulcanized indiarubber (Chap. III.). *Okonite* and certain other specially named cables are those

insulated with indiarubber mixed with various foreign substances. *Bitumen* is a mineral closely related to asphalt, and when vulcanized in the same way as rubber it forms



FIGS. 402 to 406.—Types of Cable. (British Insulated and Helsby Cables, Ltd.)

a very fair insulator for cables. Hygroscopic cables are insulated either with paper, or with a mixture of paper and fibre; and are then impregnated with resinous or mineral oils.

Concentric or double-core cables are largely employed for single-phase alternating-current work, as if single cables were used they might inadvertently be drawn into separate iron pipes, and so introduce a choking effect into the circuit (§ 214). When the two conductors are bound up in one

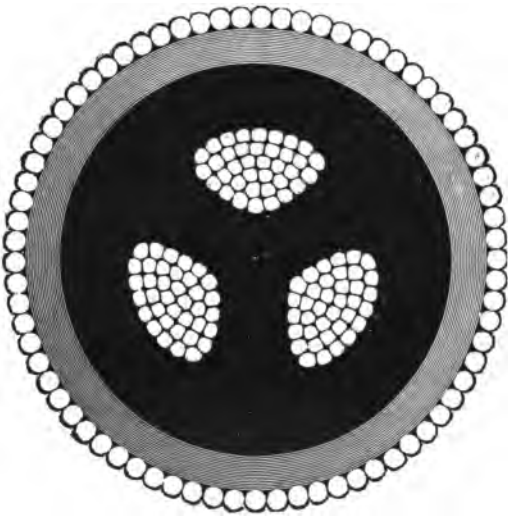


FIG. 407.—Three-core Armoured Lead-sheathed Cable. (W. T. Glover & Co.)

cable, it is manifestly impossible for such a mishap to occur. Such cables are of course used for direct currents as well.

Paper or fibre insulated cables require great care in laying, as if the lead sheathing become punctured, or a cable end be left exposed to the air for any length of time, damp will be absorbed, and the insulation of the cable will be greatly reduced at such points.

243. CONCLUSION.—This being the concluding paragraph of the book, as well as of the present chapter, it would seem fitting to make some general remarks both as to the present work and future developments that may be expected in Electric Lighting and Power Distribution. Considering, however, the very elementary character of this book, and the fact that it is only intended to help students over the threshold as it were, and to introduce them to the various departments of electrical engineering, any such summing up would be premature.

The serious and ambitious student who has accorded the Author the honour of perusing these volumes, may be informed, in the unlikely event of his not being already aware of the fact, that a much more serious course of study must be undertaken if he intend to make any mark in the diversified profession of electrical engineering.

Acquaintance with current practice and topics can only be kept up by a close perusal of the electrical periodicals, and of the journals or proceedings of the various engineering and scientific bodies, especially the Journal of the Institution of Electrical Engineers. As regards books, the seeker after knowledge will find a rather appalling number to select from. On attempting to draw up a concise and comprehensive list, the writer finds he has to abandon the task; for there are so many paths of electrical knowledge, and so many stages on each path, and so many helps to progression at each stage; that the drafting of such a list, to meet with anything like general acceptance, is really impossible. In this matter, therefore, the student must consult those under whom he is studying, or with whom he is working.

The last sentence reminds me to point out to my readers that no real knowledge of any branch of electrical engineering can be gleaned from reading alone. Study must go hand in hand with arduous work in the laboratory, in the factory, and in the open.

CHAPTER XVII.—QUESTIONS.

In answering these questions, give sketches wherever possible.

*1. Say what you understand by *electrical energy*, and show that a large current does not necessarily mean great power.

2. The declared pressure at which current is supplied to houses by mains coming from a central station is raised from 100 to 220 volts. If the percentage loss in the mains is to remain the same as before, by how much per cent. will their carrying capacity be increased when the heating limit has not to be regarded? [Ord. 1897.]

3. Enumerate briefly the principal systems of electrical distribution.

*4. When both are possible, do you consider that a direct-current system is preferable to an alternating-current one? Give reasons.

5. *Define*—omnibus bars, feeders, ring mains.

6. Why are ring circuits or mains employed?

*7. Explain the advantages of having the dynamos or alternators at a central station joined up in parallel between omnibus bars.

8. In laying down a large copper conductor to carry a heavy current, what fundamental principles would guide you in determining the size of copper for a given length of main and a given current?

9. Consider in detail the advantages and disadvantages, to the supply company and to the consumer, of changing the supply of electric energy to a district at 100 volts to one at 200 volts. [Ord. 1900.]

*9A. For what reason are many electric supply systems raising the

voltage from 100 volts or thereabouts on each side of the three-wire system, to 200 volts or more on each side? [Prel. 1902.]

10. What are the advantages of and disadvantages of supplying electric power to lamps, motors, etc., in series or in parallel? [Ord. 1901.]

*11. What is the 3-wire system, and what is the good of it? [Prel. 1895.]

*12. Describe briefly what is meant by the 3-wire system of distribution. Make a diagrammatic sketch showing a set of three conductors forming a 3-wire feeder connected to a small section of distributing network, and indicate by plus (+) and minus (−) signs the relative polarities of the conductors. [Prel. 1900.]

13. What are the advantages of using accumulators at an electric light central station? What type of accumulators would you adopt for this purpose, and why? [Ord. 1900.]

14. What is the 3-wire system of distribution, and why is it used? If any one of the three wires is to be earthed, which one would you select, and how would you "earth" it? [Ord. 1896.]

15. Sketch the arrangements of lamps and conductors known as the *series*, *parallel*, *multiple series*, *three-conductor method*, and *five-conductor method*, and describe in each case the nature and disposition of the dynamos. [Ord. 1890.]

16. What are the merits and demerits of the sub-station method of distribution? [Ord. 1897.]

17. What are the advantages obtained by using a storage battery in a central station for the public supply of continuous currents? [Ord. 1892.]

18. When are alternate-current systems better than continuous-current systems? Give your reasons as fully as possible. [Ord. 1895.]

19. Contrast the advantages of an alternating- and a continuous-current high-pressure system for town lighting, using sub-stations in each case.

20. Compare the advantages and disadvantages of the two following systems of supply from central stations:—

(*a*) The 3-wire system, with batteries for continuous-current supply.

(*b*) The sub-station system of alternating-current supply. [Ord. 1893.]

21. Modify Fig. 390, showing the switchboard connections of a direct-current station, by substituting a Highfield booster.

22. In the electric transmission of power at extra high pressure, with alternating currents, what difficulties exactly are met with in consequence of capacity, induction, and leakage? Discuss the question whether it is better to employ low-pressure dynamos with step-up transformers, or to generate at high pressure. [Ord. 1899.]

23. State relative advantages and disadvantages of the two following systems of distributing alternating currents:—

(*a*) Transformers in consumers' houses.

(*b*) Transformers in sub-stations. [Ord. 1894.]

24. What is your idea of the advisability of earthing the secondary in transformer systems? [Ord. 1895.]

25. A district is supplied with alternating current from a central station. What are the advantages and disadvantages of running the street arc lamps from the alternating-current mains or from an independent direct-current circuit provided specially for these street lamps? [Ord. 1897.]

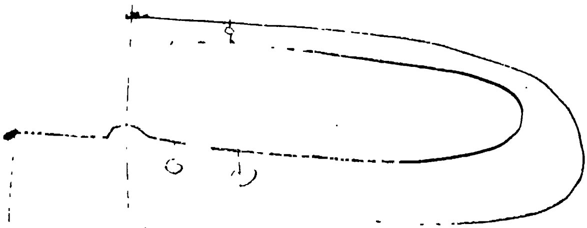
26. Give a rough sketch of a switchboard for a station with batteries and feeders and a three-wire system. [Ord. 1895.]

27. What is a "booster"? How is it used in connection with an electric tramway, and for what object? Give sketches illustrating your answer. [Ord. 1900].

*28. What special precautions must be taken in laying paper- or fibre-insulated mains? [Prel. 1898.]

*29. What are the advantages and disadvantages of using, for low-pressure mains, bare conductors supported on insulators in conduits, as compared with lead-covered paper-insulated cable drawn into pipes? [Prel. 1898.]

30. Why should alternate-current mains be either concentric or laid close together in the same channel? Has any such precaution to be adopted with mains carrying a *rectified* alternate current? [Ord. 1897.]



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